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TEACHER'S EDITION

INTERACTION OF MATTER & ENERGY

INQUIRY IN PHYSICAL SCIENCE

IME

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SECOND EDITION

TEACHER'S EDITION

INTERACTION OF MATTER & ENERGY

INQUIRY IN PHYSICAL SCIENCE

NORMAN ABRAHAM

PATRICK BALCH

DONALD CHANEY

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IME

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Foreword

Vast improvements are occurring in science education today. One of the most significant features is that new instructional materials are being developed cooperatively by experienced classroom teachers and university research scientists working together as teams. Such teams bring to the production of materials substantial knowledge about the children to be taught as well as a considerable expertise in the subject matter.

Another aspect of this new trend is the thorough trial use of the materials in actual classroom situations before release for publication. Through this procedure, preliminary copies of the teaching materials are tested for one or more school years by a number of teachers in a variety of classroom situations across the nation. Thus, before they are finally released for general use, the materials have undergone a truly experimental program of critical evaluation and development.

Interaction of Matter and Energy was produced in this fashion. The authors worked together as a writing team for several years on this particular set of materials and prepared experimental editions which were used in classrooms throughout the country. The trial program led to very substantial improvement in recasting the materials into their present form. In my opinion, this is the best possible method for the preparation of instructional materials for our schools.

Of additional significance is the fact that *Interaction of Matter and Energy* was designed specifically to articulate with the new secondary school science programs which have been developed recently with federal support and are being used very extensively. The writing team is thoroughly conversant with the new mathematics and science curricula; indeed, some of its members have themselves been active participants in the development of such science programs.

Interaction of Matter and Energy proceeds from the simple to the complex; it develops a science of investigation and curiosity in the student; it provides no pat answers in a field that is changing rapidly; and it is both interesting and comprehensible to students in our junior high schools.

It is incumbent upon all of us to help today's students develop an understanding of the attitudes, processes, and goals of science; mastery of traditional content is not enough. Fortunately, the materials available for science instruction are better now than they have ever been before. Whether or not a particular student using this book is likely to become a scientist is not very important. More important is the fact that all students using this book are destined to live in an age in which an understanding of science will be essential. I am sure *Interaction of Matter and Energy* will serve these students well at their present level of schooling.

Arnold B. Grobman
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Preface to the Student

You are about to begin the study of a new science course—*Interaction of Matter and Energy*. Most of your class time will be spent in laboratory sessions: conducting investigations, collecting and interpreting data, and arriving at conclusions that are entirely your own. In other words, most of the time you will be carrying out some kind of physical science investigation rather than just reading about it or listening to your teacher tell you about experiments and investigations that someone else did. You will be acting much like a scientist. He too must constantly study and investigate in an attempt to find answers to questions. If answers to all questions in science were known, there would be no need for further scientific research. It is doubtful that day will ever come.

The teaching of science is undergoing a great change—almost a revolution—and you are being asked to participate. You will study many aspects of chemistry and physics that were at one time reserved for students in the eleventh or twelfth grade: the behavior of atoms and molecules, a study of the periodic chart of the elements, many of the basic laws of physics, and the significance of the physical sciences to life itself.

You will come to understand that science is not just a collection of facts. Rather, science is continuing search for truth, with a bewildering number of false paths to take if one is not trained to be observant, cautious, and willing to use his own imagination and skill.

Science is a creative activity. For this reason, you will be working in laboratory situations that should allow you to be as creative as possible—situations that should cause you to avoid accepting something as fact just because someone said it is so.

Keep in mind that only eighty years ago, the concept of air travel was regarded as the silly notion of unbalanced minds. And not many years ago, the idea of man traveling to the moon and back was but a dream—something you might read in a book of science fiction.

Scientists and technologists (people who apply scientific knowledge) are now working on plans to explore the deepest parts of the oceans and are exploring the possibility of life existing on other planets. Scientific and technological knowledge and skills are being applied to pollution problems that concern every thinking person. New sources of energy are being sought to replace natural fuels. For these advancements to become a reality, we must depend heavily on the physical sciences—chemistry, physics, geology, and astronomy. Throughout this course, *you* will be challenged to understand basic principles of physical science that will prepare you to live in an era of rapid scientific and technological advancement.

Maintaining a careful record of your laboratory work will be an essential part of studying this course. Frequently you will be asked to make notes during an investigation or to organize and record data. From your notes, you should be able to interpret the results of an investigation and to predict what should happen if you carried out another investigation in a certain way. Scientists call such predictions *hypotheses.* Forming hypotheses and testing them in the laboratory (and sometimes at home) are among the many scientific skills you will use. Finally, the authors hope you will enjoy this course and would be pleased to receive your comments at any time during your study of *Interaction of Matter and Energy.*

The Authors
August 1, 1973

To the Teacher: On the Purposes and Uses of IME

Interaction of Matter and Energy (IME) is a physical science program based upon an *inquiry system* of teaching and learning. This system includes observation, investigation, interpretation, research of appropriate literature, and critical study of conclusions. Repeated use of these skills should lead students to (1) understanding of the processes of science and (2) acquisition of fundamental scientific knowledge. Students learn that "facts" accepted as true today may be modified or discarded tomorrow. They should also learn that such general concepts as the usefulness and limitations of a scientific model, the process of building a hypothesis, the role of induction in science, and other aspects of scientific activity have lasting value in understanding science and other areas of human endeavor.

Since the late 1950's, curriculum studies in biology, chemistry, physics, and earth science have brought about significant changes in the teaching of science. Among other things, these studies show that junior and senior high school students are capable of understanding science in greater depth than was previously thought possible. IME provides a background in physical science that will prepare students for these contemporary programs.

The authors do not intend to cover all aspects of physical science. We consider it more important for students to explore selected topics in depth than to attempt a (necessarily) superficial survey of the full range of physical science. In this course, technological aspects of physical science are brought into focus where necessary so that the interaction of science and technology will be recognized.

In texts as well as in teaching, premature explanations of phenomena or disclosure of "correct" answers to problems may deprive students of an opportunity to test their own abilities. Such practices tend to produce passive acceptance of fact instead of active searching for knowledge. Most IME investigations are structured so that the teacher may guide students toward achieving maximum understanding through independent discovery. Textual material is included to provide background for the laboratory activities rather than to offer answers to investigations. In some instances more specific information is given so that students will have a basis for pursuing investigations.

Rationale

Since 1966, the authors and editors responsible for the development of the *Interaction* project materials have worked in close cooperation with hundreds of classroom teachers, revising the structure and content of this course, exchanging ideas on teaching methods, improving laboratory procedures, and evaluating student achievement through testing. Teachers who are not familiar with the history, structure, and scope of the Interaction Science Curriculum Project and the IME trial program should read the "Foreword" and "Acknowledgments" in this book.[T1]

This (second) edition of *Interaction of Matter and Energy* is specifically designed to provide a strong physical science background. Such a background will help students achieve success with the new curriculum materials in biology, chemistry, physics, and earth science at secondary levels. Classroom trials have also shown that IME is very suitable as a terminal course for students who will undertake no further study of science in high school.

In preparing and revising IME, the authors proceeded on these premises:

1. Many students in junior high and early senior high school are curious and eager to learn at the outset of a new course. They *will* learn if they are given an opportunity to develop, on their own initiative, the realization that a search for knowledge can be personally gratifying.
2. In science, as in any other field of intellectual endeavor, students must be allowed to explore with freedom those subject areas they do not understand.

T1 A concise history of the development of IME and the Interaction Science Curriculum Project may be found in *Developmental Curriculum Projects: Decision Points and Processes*, by Hulda Grobman, F. E. Peacock Publishers, Itasca, Illinois: 1970, (pp. 24–30).

3. An inquiry approach to the teaching of science is essential if students are to develop initiative, investigative skills, and a realization of their potential for understanding the environment in which they live.
4. Students must realize that science is a search for knowledge based upon the best available information obtained through observation, experimentation, and reading, rather than upon superstition or passive acceptance.
5. Textual material and laboratory investigations should not be treated as separate entities. It is not even enough to assume that they are interrelated; indeed, they are indispensable to one another.
6. Science must not be treated as a subject easily learned and then forgotten. There is a need for greater incorporation of the concepts of science into the daily lives of today's students. They must be able not only to use this knowledge but also to impart it to others.
7. Much of what has been taught in conventional eleventh- or twelfth-grade chemistry and physics can be taught at the eighth- or ninth-grade level, providing that language is properly adjusted and emphasis is placed on principles and concept formation rather than on mathematical and verbal complexities.
8. Science is not in itself more important than other major areas of the curriculum, but it is essential in the education of every citizen in a modern society. Science is not to be isolated from other parts of the curriculum; rather, it embodies both accumulated knowledge and investigative methods that are relevant in almost all areas of thought and action.
9. The importance of understanding science cannot be underestimated in view of the impact science has had on every aspect of modern life—social, political, economic, technological, philosophical, and cultural.
10. There persists with some a distrust of science (or of what is popularly taken to be science)—a vague fear of an evil that occasionally escapes control to rend the peace of human societies. This fantasy needs to be dispelled, and the best method may well be to involve students in experiences that will reveal the dispassionate, impartial spirit of scientific endeavor.

One difficulty in construction or revision of the curriculum lies in determining where to begin and where to end. IME is based primarily on the premise that the major secondary-school science-curriculum studies—BSCS, PSSC, and CBA and CHEM chemistry, among others—have proved worthwhile models for the improvement of science education. With this in mind, *Interaction of Matter and Energy* has

been designed to feed into and complement such studies. Major themes and topics include the following:

Major Themes

The development of scientific behavior—particularly in experimental design, observation, and interpretation
The nature and use of scientific models
The particulate structure of matter
The conversion of energy from one form to another
The continuous interaction of energy and matter

Major Topics

Observing the behavior of matter
Models of atoms and molecules
Periodic classification of elements
Chemical and physical reactions
Approximations in measurement
Phases of matter
Models of heat and light
Objects in motion
Force, acceleration, and mass
Energy conversion and transfer
The relationship of science to technology, the humanities, society, and the environment

Methods

The integrated laboratory-text format of IME provides students with background information to prepare them for each subsequent laboratory investigation. Inversely, most investigations provide a basis for examining new problems and topics in subsequent textual material.

Each investigation is written in such a way that students are unlikely to arrive at a defensible interpretation without actually performing the laboratory work. The introductions to investigations (as well as the procedures themselves) contain clues that enable those who have a genuine interest in understanding science to interpret experimental results intelligently. Students should relate these interpretations to the text materials by means of review.

Students should keep accurate records of experimental results, interpretation of data, and other pertinent information in their own notebooks. These notebooks should become as important as the textbook; the text should be used primarily as a guide.

In the teacher's edition of IME, the teacher's material for each segment of the text follows the student pages it treats. Background information and many additional problems, investigations, demonstrations, and predictions of probable student responses are included in the teacher's material.

IME and Individualized Study

As every teacher knows, each student is unique in his or her ability to understand and achieve. Students also vary in their *desire* to learn. Some do not seem to care, even if "passing" or "failing" are at stake. They vary in emotional maturity and physical drive. Some appear to learn at a fast pace—others, at a much slower pace.

There are usually a few students in every class who appear to lack the background or ability to master certain subjects. These students may be directed toward less difficult subjects or may need remedial instruction.

Since its inception, IME has been designed and revised to provide maximum opportunities for students of widely varying ability to gain a feeling of success, to acquire a basic understanding of fundamental physical science principles, and to leave the program with a positive attitude toward science. They also gain a feeling for science that should allow them to make intelligent judgments about (1) its potential for the advancement of society and (2) its limitations.

Individualized study should permit students to proceed at a pace commensurate with their interests and abilities. The adaptability of IME for individual study is achieved in several ways. Most sections provide investigations titled "On Your Own." Most of these investigations may be carried out on an individual basis after school or at home. They vary from very easy to fairly difficult. Each relates to a more structured investigation that students have previously performed. Thus, provision is made for students to use their own creative ability and imagination to solve a particular problem in their own way without continuous supervision by the teacher. (Another potential advantage is that parents may at times become involved in carrying out these special kinds of investigations.)

Also, many of the standard investigations labeled "per team" may be assigned on an individual basis.

A number of "Photo Essays" are included where appropriate. Most are accompanied by questions about the photos that can be answered by individual students or by teams of students.

We urge that you "follow up" each student's individual efforts with private or classroom discussion. Teachers report that many students become discouraged or "lost" when left on their own for too long a time without review and discussion with the teacher or the class.

Individualized study may uncover latent talent. A very bright student may be classed as a poor achiever simply because he is bored with the routine of school life. We all know of creative or highly successful individuals—leaders in the most challenging professions, businesses, or trades—who were "failures" in their early schooling. A classic example is Albert Einstein, who is said to have failed his high school mathematics courses.

Evaluation: Objectives and Tests

LEARNING GOALS AND OBJECTIVES

Science is both an accumulation of knowledge and a variety of processes by which this knowledge is obtained. Scientific knowledge, comprehended and applied, is an important component of literacy (in the fuller sense of that quality). But understanding the processes of science, including problem solving, experimental design, and data analysis, can help students learn how to weigh and consider evidence and opinions. A grasp of both facets of science—knowledge and processes—is required if students are to become *scientifically* literate.

The authors believe that each student should encounter scientific questions in ways that arouse interest and encourage a desire for further investigation. IME stimulates curiosity by asking questions and posing problems which invite students to actively participate in each of the investigations. Students are then asked to use a variety of inquiry skills as they seek answers. In doing this, students also develop the confidence and initiative necessary for self-instruction and for inquiry activities. Ultimately, this procedure can lead to an understanding of the nature of science that will long endure.

INTELLECTUAL SKILLS

Intellectual skills can be defined as those intellectual behaviors exhibited by the student in perceiving his surroundings, developing concepts, seeing relationships, and applying knowledge. In the table on page *xvi*, these skills are listed with examples of processes of science each student should master with some degree of competency.

INTELLECTUAL SKILLS	INQUIRY PROCESSES OF SCIENCE
	To become scientifically literate, each student should be able to demonstrate that he can:
PERCEPTION	Observe carefully Describe accurately Manipulate laboratory apparatus Measure accurately Construct and use equipment
ORGANIZATION	Identify variables Compare and classify or group materials
CONCEPTUALIZATION	Offer hypotheses Raise questions Sort and classify data Recognize sequences or trends Analyze information Make inferences from data Draw conclusions Distinguish between variables Determine the effect of variables Isolate and manipulate variables
APPLICATION	Apply information to new situations Investigate Design experiments Predict the effect of variables on experimental results Propose models Evaluate models

More specific "Learning Objectives" are listed in the "Previews" to each section of IME as options for teachers who find such objectives useful or necessary. The introduction to the teacher material on each investigation gives the most specific synopsis of the material and the expected response.

You should be concerned with maintaining the open and inquiring character of the investigative approach throughout the IME program. We recognize the current and widespread efforts to develop comprehensive lists of highly specific objectives as conscientious and probably constructive where teaching, learning, or subject matter fail to focus on well-defined goals. Nevertheless, any good idea can be converted to a liability if carried to excess. Potential damage to an inquiry-oriented program lies in over-zealous use of specific objectives for every student with every task or opportunity for exploration. Spontaneity, surprise, innovation, and fun may be diminished or lost. The authors have, therefore, provided only major "Learning Objectives" that best relate to each IME section; these can be used to trace and

evaluate student progress. The objectives may not be needed by teachers who wish to give students maximum scope to develop individual interests and abilities.

ATTITUDES

Another important goal of this program is the formation of positive attitudes towards science. These can be classified as the attitudes exhibited whenever the student inquires, behaves in a scientific manner, takes risks, or demonstrates creativity. Included here are some suggestions to aid you in recognizing each attitude:

ATTITUDES	EXAMPLES The student expresses positive scientific attitudes when he:
INQUIRY	Initiates questions voluntarily Demonstrates curiosity about problems, equipment, or suggested procedures Uses all of his senses to explore, observe, hypothesize, and question Relates home or environment to classwork Investigates the same questions in several ways Voluntarily reads other science materials
CRITICAL THINKING	Offers ideas divergent from commonly accepted views Questions authoritarian statements Supports his ideas with a variety of observations Insists on hearing all available evidence before offering conclusions Evaluates and reevaluates his beliefs as he gathers evidence Persists in trying to solve problems Considers all conclusions tentative and open to new interpretation as new evidence is uncovered
RISK TAKING	Willingly subjects himself to possible criticism or failure Expresses his feeling, opinions, or criticism in the presence of "experts" in a specific field of science Participates freely in discussions and laboratory work Indicates a willingness to try new approaches
CREATIVITY	Displays a variety of insights and reactions to problems Pursues investigations by innovative applications of equipment or approaches Suggests other variables for testing Has several solutions for each problem Participates in additional research

To adequately and fairly measure students' attitudes, a variety of data collecting means must be used—observation, questioning, and discussion, on a one-to-one basis as well as in small groups. It is hoped that you will review these lists periodically as a reminder of these goals. The development of these general attitudes and skills should become an everyday goal; their usefulness is not limited to any particular section or investigation.

To test for all possible goals and scientific attitudes related to any program would be impossible. However, we do recommend that you periodically review the significant goals for each section and for each investigation.

TESTS

Four "Quarterly Achievement Tests" and two "Final Examinations" are available from the publisher. Answer sheets, scoring keys, instructions for administering tests, and commentary on specific test items are provided. These tests have been specifically designed to measure student progress on two levels of learning categories: (1) information and comprehension and (2) science skills.

In addition, at the end of each section, teachers will find a list of ideas for testing student's mastery and understanding of basic laboratory techniques. These "practical" items were particularly well received by users of the first edition of IME.

Schedule

Actual teaching time for the various sections of IME will vary greatly, depending on such factors as available class time, familiarity with the course, student interest, and the individual interests of the teacher. Listed here is one possible schedule, based on the amount of material in each section. It assumes a thirty-six week school year. Consider it to be a general guide rather than a rigid timetable.

SECTION	WEEKS	SECTION	WEEKS	SECTION	WEEKS
One	1	Six	2	Eleven	3½
Two	2½	Seven	3	Twelve	4½
Three	2½	Eight	4½	Thirteen	2½
Four	2	Nine	2	Fourteen	1
Five	3	Ten	2		

Equipment and Supplies

Consumable and nonconsumable materials necessary for implementation of the course are listed in Appendix D, page 350. Classroom

sets of nonconsumable items, glassware, and chemicals are available from the publisher, as specified in the appendix.

Use of this course is not contingent upon purchase of equipment from Rand McNally & Company. Quantities listed in Appendix D are recommended for a class of thirty-two students, but many teachers have successfully completed the course at very modest expense by using materials already in stock and by constructing many items in the school shop or by obtaining them locally.

Many, though not all, of the materials needed for teaching IME are contained in four packages available from the publisher. These are a chemicals package, a glassware package, a package of equipment for a class of thirty-two students, and a teacher materials package.

Acknowledgments

The Interaction Science Curriculum Project has been, we believe, the first curriculum project of truly national scope and size, wholly funded and supported by a private publisher. As such, it owes an enormous debt of gratitude to nearly 1500 teachers and more than 100,000 students who have tested and evaluated the experimental editions of the three Interaction books in the past seven years.

The Interaction Series includes *Interaction of Matter and Energy*, *Interaction of Man and the Biosphere*, and *Interaction of Earth and Time*.

The first book in the series, *Interaction of Matter and Energy* (IME), was published in 1968. The authors and the publisher believe that a science program should be revised at least every four to five years to keep up with the advance of science.

In revising IME, the authors were guided by nine consultants from various areas of the country, most of whom are experienced IME teachers. In addition, suggestions for changes were received by mail from practicing teachers and are incorporated in this revised edition.

The frank comments, criticisms, and suggestions from our consultants and many other teachers have contributed immeasurably to the final product. Science supervisors, principals, and other educators have contributed directly and indirectly to this revision of IME. Though they cannot all be listed individually, they have our deepest thanks.

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Table of Contents

SECTION ONE

A Way to Begin

SECTION ONE

A Way to Begin

(pages 1–17)

IMPORTANT: *If you have not carefully read "To the Teacher, on the Purposes and Uses of IME" (pages x–xix) please do so now. Also, please study the suggestions for using IME on an individualized student basis, allowing students to proceed at their own pace.*

Preview

The activities and demonstrations in Section One focus on scientific processes rather than on specific scientific content. The facts are not considered as important as understanding the processes by which they are discovered. Whenever possible, students should make observations and see relationships based on their own activities. Maintaining a notebook as a record of these observations is essential. The first activity points out some of the problems in making and communicating accurate and complete observations. The demonstration and discussion which follow illustrate the differences between observations and interpretations. "Getting Involved" is the first student investigation. Its informal structure is intended to put the student at ease and to invite him to be creative. "Inquiry Demonstration: Asking Questions" illustrates the idea that science also involves processes such as formulating questions from observations and interpretations. Every effort has been made by the authors to avoid giving away answers which students are asked to find for themselves.

Section One begins with a story about Cro-Magnon cave dwellers. It discusses what their drawings and carvings on cave walls might tell us of their period in the history of mankind. A suggestion is made that the dawn of what we now call science *may* have occurred some twenty-five thousand years ago. Whether such a story could be true, we shall never know.

In "Trying to Define Science," students are further introduced to what science is about. Students learn that there is not *one* scientific method, that science is complex, and that doing what scientists do is the best way to understand the meaning of science. Following this they are asked to become involved by observing the behavior of two suspended objects (actually a compound pendulum). Students are not *told* why the "suspended objects behave the way they do." Instead they carry out further investigations of the problem on their own—perhaps at home—and try to express their observations in some meaningful way.

In "The Modern Scientific Community," students learn about the contributions to science of men and women from many nations and ethnic groups. Science is an international and multiracial activity.

Students should see that science is *not* divided into completely separate disciplines. Instead, science is an integrated whole involving chemistry, physics, biology, and many other fields in many different combinations.

The silhouette of a Cro-Magnon hand opens Section One. It is taken from the cave at Peche-Merle, in France, and is tens of thousands of years old. The artist apparently placed his or her hand against the cave wall and traced around it with pigment. It is used here to signify that, though the human brain is the most important tool of science, the human hand is certainly a close second.

PLANNING AHEAD

The following suggestions are included to advise you about activities that may require advance planning or preparation:

The inquiry demonstration on page 8A requires some common objects. Many of them are obtainable from your home or desk. You will need one small paper bag per student.

The inquiry demonstration on page 8C requires dialysis tubing, Karo syrup, or sugar. Check the materials list.

"Getting Involved—Investigating," on page 7, requires one setup per team as shown in Figure 1 • 5.

The inquiry demonstration on page 13A requires concentrated HCl and NH_4OH. Finding suitable dishes may be a problem.

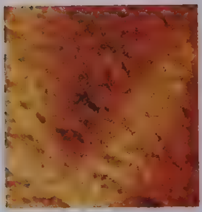
Not all items needed are listed in this "Planning Ahead" section. Be sure to check the material lists for each demonstation and investigation to see that you have the equipment and supplies on hand.

Check the references listed at the end of each section for titles which might be ordered for the school library.

LEARNING OBJECTIVES

Given the opportunity to inquire, to investigate, to interpret data, and to offer hypotheses about the activities in this section, most students should be able to—

- Accurately observe and describe some properties of a variety of objects;
- Sort and organize data to help determine the probable nature of an unseen object;
- Observe and carefully describe a simple chemical reaction;
- Offer a reasonable, simple hypothesis to explain the interaction of matter and energy observed in a double pendulum;
- Begin to offer interpretations of data;
- Use a variety of senses in the collection of data;
- Explain the tentative nature of interpretation;
- Explain scientific investigation as a special kind of human activity.



Drawings on the walls of ancient caves near Lascaux, France, and Altamira, Spain, suggest that early cave dwellers recorded some of their observations and experiences (Figure 1 • 1). These drawings *could* represent some of the earliest recorded "scientific" observations.

Suppose we imagine that twenty-five thousand years ago a Cro-Magnon man was telling the children of the tribe about his experiences on a hunt. He may have used some drawings to show the best method of killing a running bison: the hunter had to aim his spear a certain distance ahead of the animal so that bison and spear would reach the same spot at the same time.

Figure 1 • 1. Drawing of a prehistoric bison by a Cro-Magnon artist, from a cave near Lascaux, France. The drawing is about 4 feet, 6 inches long, painted in reddish brown and black.

Figure 1 • 2. Cro-Magnon hunters and prehistoric bison.

At first Cro-Magnon man probably learned successful hunting methods by trial and error. Because failure to kill bison meant going without food, the need to improve hunting technique was vital. To succeed, the hunter learned to aim ahead of the running bison—to throw his spear toward a point where no real target existed at the time. If incorrectly aimed, the spear would miss the animal or cause only a minor wound. In either case, the bison would escape.

Figure 1 • 3. Wounded bison.

Figure 1 • 4. Dying bison with spear in the region of the heart.

Perhaps the hunter recorded his data, using the wall of a cave as his notebook. His "students" could then ask questions: Why does a bison usually survive when a spear pierces its hind quarter? Why does a bison usually die when a spear pierces its front quarter? What is so vital about the front of the bison? Is its "life" located in only one spot? Answers to these questions might have led to additional drawings (Figures 1·3 and 1·4). One drawing might have shown a spear piercing the front quarter of a bison; another, a spear piercing the hind quarter. The drawings may have been the work of one man, but perhaps the observations were taken from the experiences of many hunters.

This story is, of course, only one of many possible explanations. Cro-Magnon man may not have used his drawings as a means of instruction. Indeed, some researchers think that the cave drawings were used entirely for magic and rituals. We will probably never know the exact purpose of these drawings, since there is no written history on which we can base our interpretations.

The drawings on the walls of ancient caves do exist, however, and perhaps in a crude way early man did use what we call a "scientific approach." If he attempted to explain why a spear in the chest of the bison, near the heart, was more likely to kill the animal than a spear in its hind quarter, we could say he was acting like a scientist.

Trying to Define Science

No one knows exactly when science began. Even if the earliest written descriptions of human activity were found, we would still be a long way from the beginning of science. Writing and record keeping developed long after man began observing and thinking about his surroundings. But because science is a special kind of *human* activity, at least we can say that science began some time after man appeared on earth.

Because science is a *special* kind of activity, we cannot say it began when man first thought or when he first looked at a rock, a tree, or the sun. He may have done these things for many thousands of years before he thought or did something scientifically.

Notice, also, that we say science is a kind of *activity*—not just a body of knowledge. What do we mean by scientific activity? By scientific thinking (which is a very important kind of activity)? You could read many books about science, its history, and its achievements. You might come to understand what we mean by saying that science is a special kind of activity. But to learn what science is just by *reading* about it would take a very long time—years, perhaps.

Maybe a more direct way to understand science is to *do* what a scientist does. This course is designed so that you will spend most of your time doing things—investigating—rather than reading. How scientific your investigations are will depend on your interest and care in observing, recording data, interpreting results, and drawing conclusions. These are basic scientific skills, and they are used by the professional scientist no matter how simple or how complicated the question he seeks to answer.

As this course proceeds, you will find that science involves many methods—that it is a complex activity which cannot be described in a single sentence, paragraph, or chapter. There is no one scientific method that can be used in all cases. The method that is used depends on the problem or question, and on the investigator.

Though science is complex, the popular notion that scientific work requires huge laboratories and vast amounts of complicated apparatus is often incorrect. Much of the creative work in science is performed with little more than the natural senses, an inquiring mind, and (perhaps) a pencil and paper.

The scientist does not take his surroundings for granted. He seeks explanations for what he observes, no matter how commonplace the event. Now you will have an opportunity to observe a simple interaction of matter and energy. If you make an honest attempt to explain what you observe, you will be acting much like a professional scientist.

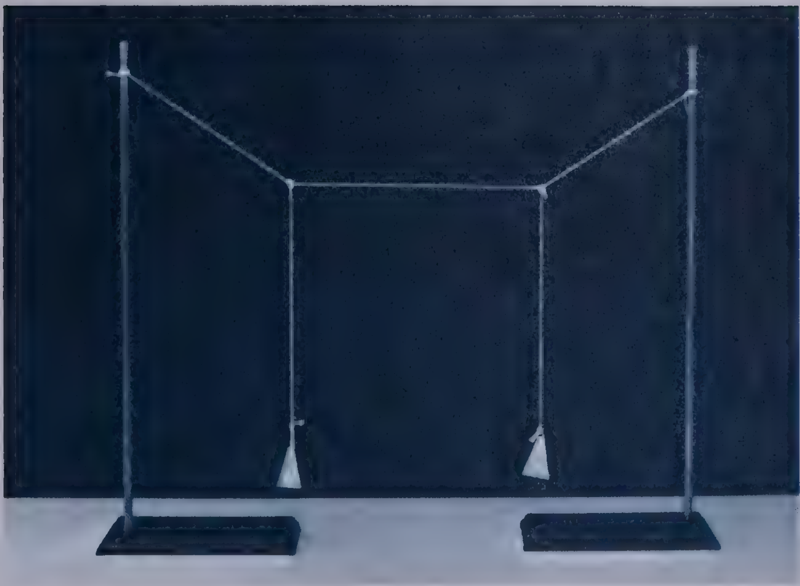


Figure 1 • 5. Setup of strings and objects. What effect will the motion of one object have on the other?

Getting Involved—Investigating

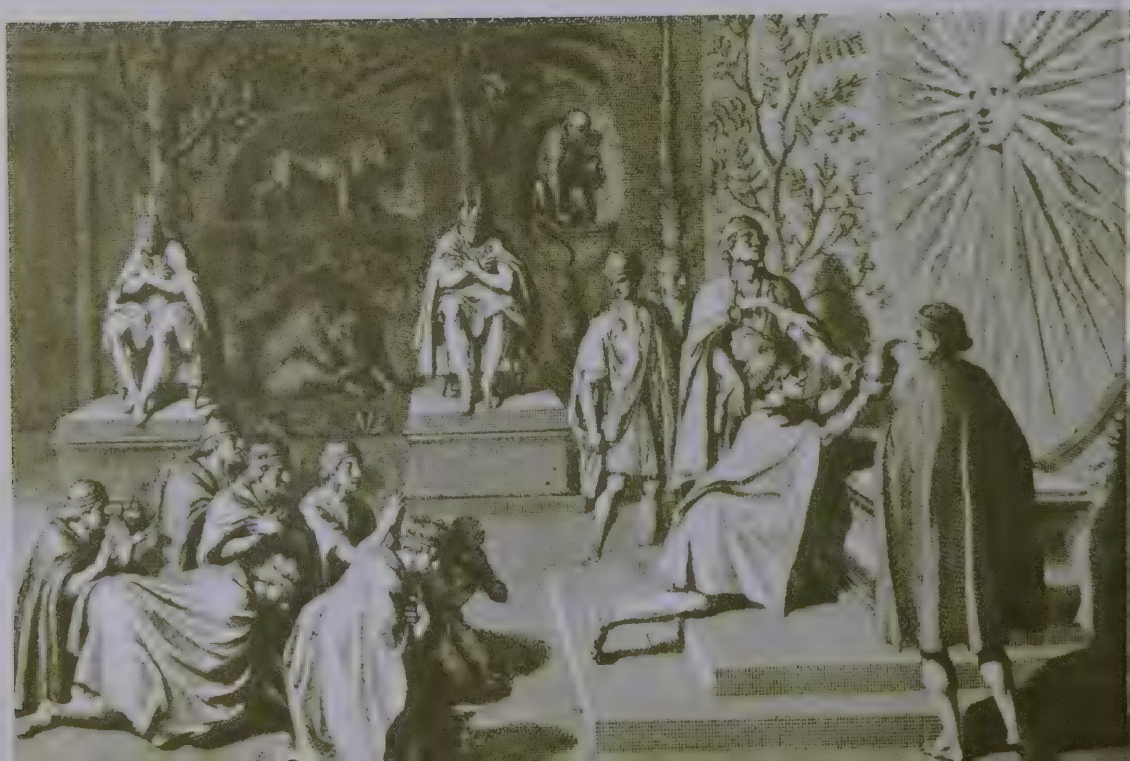
Set up the apparatus shown in Figure 1 • 5. Almost any kind of support will do (chairs, ring stands, etc.). The objects hanging from the strings should weigh about 4 ounces each. Fishing weights, bolts, or other common objects may be used. The strings supporting the two objects should be about the same length, with enough distance between them to prevent the objects from hitting each other when they swing. Without bending the horizontal string, pull one of the objects toward you and release it. Observe carefully for two or three minutes and record what happens to each object.

You may find the behavior hard to explain. But where do you look for an explanation? First, you may attempt to build one on your own observations. Or you may simply decide to accept, without question, an explanation from someone else. The scientist requires that an explanation agree with what is observed. Your explanation for the behavior of the suspended objects must agree with all your observations.

Scientists often observe events they cannot immediately explain. Their observations may form the basis for explanation as they repeat experiments, try different arrangements, and make new observations. You will carry out these kinds of testing activities during the course. But you need not wait for the investigations which follow to gain such experience. Begin to test your explanation now. You might change the arrangement of the suspended objects or change the number of objects suspended. You might use different weights or change the lengths of the strings.

These investigations can and should be done at home. Perhaps later in the course you will be better able to explain the results of these investigations. But you can make many observations now—and the more observations you make, the more confidence you will have in your explanation.

Figure 1 • 6. Before the arrival of the Spanish, in the sixteenth century, the Inca civilization of South America worshiped the sun as the source of all power and the cause of all events beyond the control of man. How might the Incas have come to believe this? In what ways were their observations more limited than those of modern man?



A Way to Begin

(page 2)

Any comments about the "scientific" observations of the prehistoric artist are purely speculative. Students may suggest that the artist must have seen many such animals before he could reproduce one, as a wall painting. He must have carefully observed and noted the relative sizes of the parts of the bison to paint one so accurately—the choice of red and black pigments might indicate that he noted the natural colors of the pelt. The position of the spears in the back might indicate that he had seen several animals killed or wounded by hunters. The closed eye and lolling tongue might indicate that he had once seen a dead animal. Although none of these statements can be made with certainty—scientific curiosity encourages speculation, and then collection of additional data, and perhaps eventually interpretation. In this case no further data may become available.

INQUIRY DEMONSTRATION: Observing and Describing

(Teacher Only)

This activity helps students to understand the need for careful observation and to appreciate that observation is a skill which must be practiced. They may also learn that often one of the most difficult tasks is to report observations in a way that others can understand.

MATERIALS

Paper bags

Common objects such as clothespins, band-aids, toothpicks, matches, ice cube trays, etc.

PROCEDURES

A. Place one object in each bag before class begins.
B. Distribute the bags to students. Tell them they may look in their own bag but must not let anyone else know what it contains.
C. Have each student write a description of the object observed. The description may include shape, size, color, and anything else that can be found out by looking at the object, but not the name of the object or how it is used.

D. As students finish their written descriptions, check each one to make sure they have followed the rules.

E. Have the students, working in pairs, attempt to identify the objects in their partners' bags, from clues given by their partners. Allow some time after each clue for response.

F. Summarize the activity by pointing out that careful observation and description are essential skills in science and require much practice.

Getting Involved—Investigating

(pages 7–8)

This investigation illustrates an example of the interaction of matter and energy and offers the students a challenging phenomenon to observe.

Students should not get the idea that science necessarily involves complicated equipment. The activity with suspended objects is intended to establish a pattern for *student* involvement in carrying out future investigations, making observations, and when possible modifying investigations for further study at home. Before beginning this activity, divide the class into investigation teams of from three to six students, assigning each team its own working station and set of materials.

MATERIALS (per team)

2 ring stands or other supports
3 pieces of string
2 weights such as fishing weights or bolts (about 4 ounces each)

Have the students set up the apparatus as shown in Figure 1 • 5. When one of the weights is set in motion, energy will gradually be transferred to the other weight.

It is preferable at this time to concentrate on the concept of the transfer of energy from one object to another, and not on the principles of a pendulum. Students will investigate the pendulum in Section Nine. Students should be encouraged to continue their observations at home and to vary the conditions of the experiment so that they can test and refine their explanations for the observed behavior.

Variables they may test are the length of one of the strings attached to the weights, the length of the supporting string, the distance between the two strings attached to the weights, and the number of weights.

INQUIRY DEMONSTRATION: Interpreting Data

(Teacher Only)

In this demonstration, help students to distinguish between their observations and the interpretations they draw from the observations. Don't expect students to produce the accepted concepts about semipermeable membranes. Encourage them to suggest any reasonable explanations of the events they observe.

MATERIALS

- Dialysis tubing
- Scissors
- Concentrated sugar solution (Karo syrup, molasses, or table sugar dissolved in an equal volume of water)
- Glass tubing, 30 cm
- One-hole stopper, to fit end of dialysis tubing
- String or wire
- Large jar or beaker
- Meterstick
- Ring stand and clamp

PREPARING FOR THE DEMONSTRATION

A. Cut off a piece of dialysis tubing about 5 inches long. Wet the tubing to make it flexible and tie a knot in one end. Fill the tubing with sugar solution to within 1 inch of the open end. Insert the stopper and the glass tube. Push the stopper in far enough so the sugar solution rises in the tube to a level just above the top of the stopper. Tie the tubing tightly against the stopper with string or wire.

B. Carefully rinse the outside of the dialysis tubing with water.

C. Place the dialysis tubing in a jar of water.

D. Attach a ruler or meterstick to the glass tube with string or rubber bands. Support (with a ring stand) the ruler and the attached tube in a vertical position. Adjust the apparatus so that the bottom

of the dialysis tubing is not resting on the bottom of the jar (see Figure T-1 • 1).

E. Measure and record the level of the solution in the glass tube. Repeat this measurement at regular intervals during the class period.

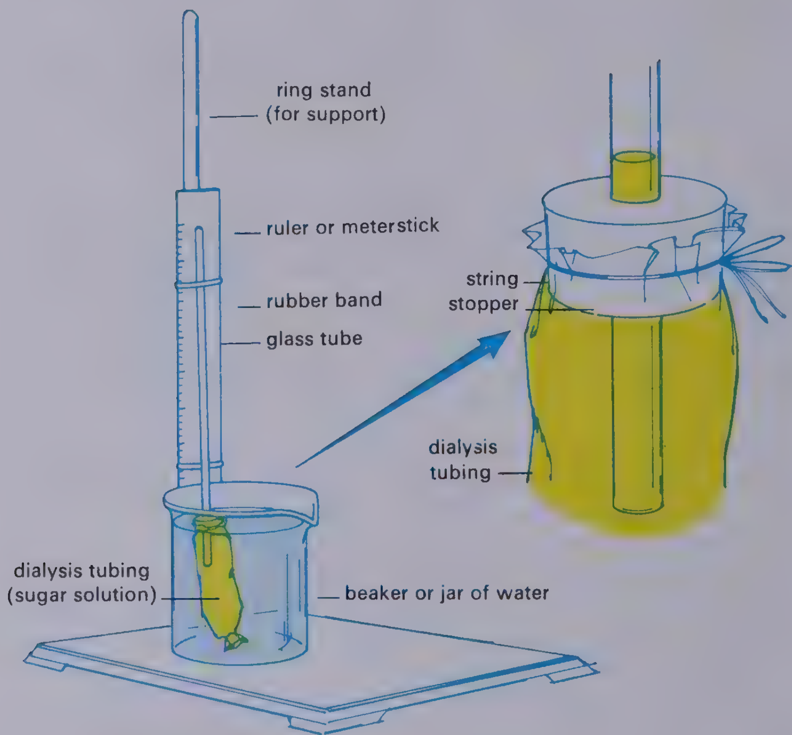


Figure T-1 • 1. Completed set-up for Procedures A–E. The detailed enlargement on the right shows the correct procedure for connecting the dialysis tubing, stopper, and glass tubing.

INTERPRETATION

The primary purpose of these interpretative questions is to make students aware of some different kinds of interpretations. They will not necessarily arrive at accepted answers. You may find it helpful to ask leading questions or to have students evaluate plausible and implausible explanations which you propose.

1. Where does the extra liquid come from? *(Only two explanations for the rise of water appear to be reasonable: the membrane might have shrunk, thus reducing the capacity of the bag; or water might have passed through the dialysis membrane from the jar and entered the bag.)*

2. Why did the liquid move as it did? *(All molecules are in motion. Because of this motion, they tend to scatter from an area of greater concentration to an area of less concentration. At any given instant, more water molecules will strike the membrane from the water side than from the sugar-solution side. In other words, if water molecules can get through the membrane at all, more will pass into the bag than will pass out, because of the different concentrations on the two sides.)*
3. Predict where the level of the solution will be at the end of one or two hours. *(Unless a leak develops in the membrane, the liquid should continue to rise at a fairly steady rate. Approximate values could be calculated using the proportion:*

$$\left(\frac{\textit{observed change in height}}{\textit{observed time interval}} = \frac{\textit{predicted height}}{\textit{one hour or two hours}}.\right)$$

4. What would happen if you added a lot of sugar to the water in the jar? *(Students are not expected to provide a specific answer, and any reasonable prediction should be honored. After making the prediction, they may want to try the experiment. If the concentration of sugar in the jar is equal to that in the bag, the level of solution in the glass tube will slowly fall until it is equal to the level of water in the jar. If the concentration of sugar in the jar exceeds the concentration in the bag, water will continue to diffuse out of the bag. Diffusion of a substance takes place from a region of higher concentration to a region of lower concentration* of that substance.)

Asking Questions—Why Is It So?

One of the most rewarding activities in this course will be the opportunities to recognize problems and ask questions. Often questions will occur as you carry out procedures in the investigations. "Why are we doing this in this particular way? What would happen if that were left out? Why is it important to record this information? What major problem are we trying to solve? What concept or principle do these results support? Does this happen anywhere else? Are there examples of this laboratory experience that happen in everyday life?"

One of the difficult parts of asking questions is how to ask the questions that will lead to procedures which might shed some light on the problem. As you proceed in this course, you should improve your ability to ask, "What questions do I need to have answers to at this time?" With this ability, the search for useful information will become easier and more rewarding. The search for answers or evidence which suggests solutions for problems is the essence of scientific research.

In the following demonstration, you will have an opportunity to ask questions.

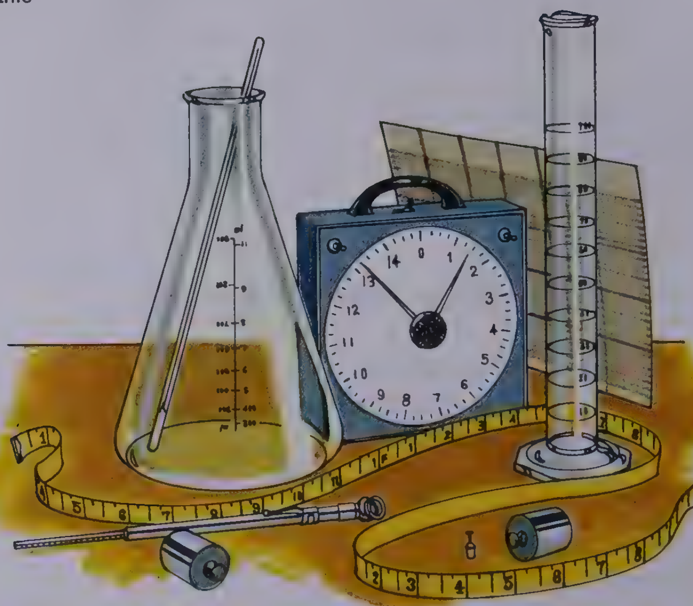
The Modern Scientific Community

Through much of history, man has sought explanations for his observations. When observations have been too limited, his explanations often have been incomplete or even wrong. Primitive men often used spirits—good or evil—to explain events for which they could find no visible causes. In the cultures of American Indians, for example, many events in nature were believed to be the work of spirits. Among primitive tribes of Africa, the Amazon, Australia, New Guinea, and other regions, evil spirits are blamed for floods, droughts, disease, and earthquakes. Good spirits are given credit for a large crop or for the recovery of a sick person. For thousands of years, people of many countries and races have been observing, investigating, and developing theories about their

This painting from the wall of an Egyptian tomb shows metalworkers heating gold ore and pouring off molten metal into casting molds. What scientific techniques are shown in this painting?

Science and Technology

Figure 1 • 7. Technology involves the development and application of scientific information for man's use and benefit. Shown here are some achievements in technology.



Uses of numbers are endless in this age of huge quantities and precise measure. Modern numbers combine symbols and systems developed by the Arabs, Persians, Egyptians, and Hindus. How are these kinds of tools important to science? What purpose does each tool serve?

Nearly two thousand years ago, Roman engineers designed aqueducts like this one to carry water from springs to far-off cities. The water flowed through a trough above the arches. What techniques (methods) of science are suggested by this accomplishment? How is the transportation of large amounts of water different today?

Laboratory of a sixteenth-century alchemist. The alchemist's techniques often resembled those of modern science, but his efforts to convert common metals into gold were unsuccessful. Suggest some experiments the alchemists might have attempted.

The Chinese invented gunpowder and used it in several kinds of weapons. Here a warrior is rocketing arrows toward the enemy. What scientific discoveries had to come before the events shown here?

surroundings. Much of our present knowledge is the result of the work of early Egyptians, Chinese, Romans, Greeks, Arabs, and many others (Figure 1 • 7).

Modern science, too, is international. We have great advantages which the ancients did not have. Our means of recording and communicating spoken or written information are much more rapid and more accurate. An announcement of a new scientific discovery, idea, or method may spread around the world by radio and television within minutes. Air transportation makes it possible for scientists to attend international conventions or to visit the laboratories of other scientists anywhere in the world.

Figure 1 • 8. Science and communication. Unless ideas and information can be communicated from one person to another, there can be no science. This Egyptian painting, nearly five thousand years old, gives certain information. Examine it closely and discuss what the information and ideas in the painting might be. Compare the advantages and disadvantages of this kind of communication with modern methods.

For today's scientific community, distances and (in most cases) national boundaries no longer present obstacles to the movement of men and information. In somewhat the same way, the major branches of science—chemistry, physics, biology, astronomy, and so on—are no longer separated by distinct boundaries. Nor is there a sharp dividing line between science and the many branches of *technology*—those fields in which the sciences are applied, such as engineering and medicine. All branches of science and technology are related, some very closely. In the twentieth century an overlapping of interests and skills has resulted from the increasing complexity of scientific work and the problems that scientists have been asked to solve. Examples of such enormous problems are not hard to find: pollution of the earth's water and atmosphere, the population explosion, the need for vast new energy resources. Finally, consider our efforts in the exploration of space. Using knowledge developed by scientists, engineers design and develop rockets and fuels. Physical scientists use the rockets to collect information about the earth's atmosphere and the space beyond. Medical doctors make sure that conditions within the capsule provide a healthy atmosphere for the astronauts; and biologists are interested in the possibility of life on other planets. Each group must cooperate with and depend upon the skills of men in other fields of specialization.

The possibility of life on other planets captures the imagination of young and old alike. Whether or not we find answers to questions about life on other planets depends on how well we use our skills and knowledge. We *can* say that the search for knowledge about our surroundings is not one guided solely by physicists, chemists, biologists, astronomers, or engineers. It demands the best in ability from specialists in all areas of human activity and learning. Through cooperative effort, we may someday understand what lies beyond our earthly environment.

Of course, few of us will play any direct role in the exploration of space. Unless you plan to pursue a career in physics, chemistry, biology, or a related field, you may wonder how the study of science can be of any value. There are several answers that are worth considering.

INQUIRY DEMONSTRATION: Asking Questions

(Teacher Only)

This demonstration, like the study of suspended objects, illustrates the investigative nature of the course. Many of the observations made by students during the demonstration will not be explained until later in the course. At this time help them to list "questions I would like to have answers to." Do not supply answers and do not comment on the "correctness" of students' explanations. After they complete Section Five, you may want to refer them back to this demonstration and ask for answers to their questions and for better explanations based on what they have learned to date.

MATERIALS

Concentrated hydrochloric acid (HCl) in closed reagent bottle
Concentrated ammonium hydroxide (NH_4OH) in closed reagent bottle
2 dishes (1- or 2-inch watch glasses or culture dishes)
1 glass bowl to fit over both of the smaller dishes (6-inch diameter)
Black poster paper (1 x 2½ feet)

CAUTION: *Both hydrochloric acid and ammonium hydroxide are very corrosive. Warn students to avoid touching these chemicals or inhaling the fumes.*

PROCEDURE

Half fill one dish with concentrated hydrochloric acid. Stopper the reagent bottle and remove it from the demonstration desk. Place the other dish about 2 feet away from the dish of hydrochloric acid and half fill it with ammonium hydroxide. Stopper the bottle and remove it from the demonstration desk. Do not place the reagent bottles close together, since the reaction may occur near them also. Ask your students to list their questions.

Slowly move the dishes toward each other and ask the students to record their observations. When the dishes are less than 1 foot apart, a white "smoke" should be visible. This is ammonium chloride formed by the combination of gaseous ammonia molecules with gaseous hydrogen chloride molecules. Students are likely to call it *smoke* or *steam*. Stand the black paper on edge behind the dishes; curve the ends around the two dishes to make the smoke more visible. This will also decrease the effect of air currents on the particles.

After the students have observed the formation of ammonium chloride, move the two dishes together so they touch and invert the

bowl over them. Near the end of the class period, remove the bowl and examine the dishes.

There will be a much heavier deposit of ammonium chloride around the container of hydrochloric acid than around the container of ammonium hydroxide (Figure T-1 • 2).

Figure T-1 • 2. The formation of ammonium chloride. The dish on the left contains hydrochloric acid; the one on the right, ammonium hydroxide.

Ask your students to list additional questions. Some questions students might ask are as follows:

a. What are the two liquids? (Are they both water? etc.)
b. Why do they smoke if they are placed together?
c. Does one of the substances drift over to the other one?
d. Why can't you see anything coming out of the dishes when they are apart?
e. Do the particles get out of the containers?
f. What substances are in the solution?
g. What is the white smoke?
h. Why does the white material form closer to one container than to the other?

Answers to questions such as these must be withheld at this time. Encourage further questions, discussion, and recording of possible explanations. Students must become accustomed to the absence of

quick, "right" answers; this is, of course, part of the scientific experience. Later sections of the course provide bases for determining answers to the preceding questions. Reassure students who become frustrated by questions that are not answered. You might tell them that recognition of those things that we do not fully understand is an essential element of science—they have successfully completed the assignment when they have listed questions which can be investigated. They will discover some of the answers in later sections.

PHOTO ESSAY: SCIENCE AND TECHNOLOGY

(pages 10–11)

Egyptian Wall Painting • This series of drawings seems to communicate the idea that these early men could produce gold ingots by melting and reducing ores. They knew about using bellows to increase the air supply to the furnace to raise the temperature—the last picture could indicate use of the ingots for trade.

Roman Aqueduct • The design of the aqueduct shows that the Romans knew of the differences in elevations required to make water flow. They also were aware of the need to build supports and arches strong enough to carry the weight of running water. The arches and open space indicate that they knew how to build walls which needed a minimum amount of material to permit strength but also visibility and access to both sides.

The gigantic pipelines and irrigation ditches used today are not drastically different from the Roman aqueduct. Pipes allow us to transport "clean" water with little evaporation, but these pipes must still be supported as they cross ravines or valleys in a similar way. Steel frames or arches may replace stone bridges or walls, but the system is similar. Technology has improved upon the material but the idea is similar.

Alchemists • Students might suggest that alchemists could melt cheap metals together in various amounts in attempts to approximate gold. Yellow colored substances could be added to lead—salts or acid could be mixed with irons. Several compounds—each with a quantity of gold—could be mixed, melted, or added to some less precious metal.

Rocket • Students may suggest a variety of observations and experiments which could have been performed earlier. The experiments on explosives, nozzles (or controlled openings), weight balance which

promotes movement, trajectories, delayed fires, or explosives would all have to have been worked out at some time prior to the production of rocket weapons.

Measuring Tools • These tools are used to measure or to determine—

1. time (clock)
2. length (tape measure)
3. mass (weights)
4. temperature (thermometer)
5. pressure (pressure gauge)
6. volume (graduated cylinder and volumetric flask)
7. relationships between variables (graph paper)

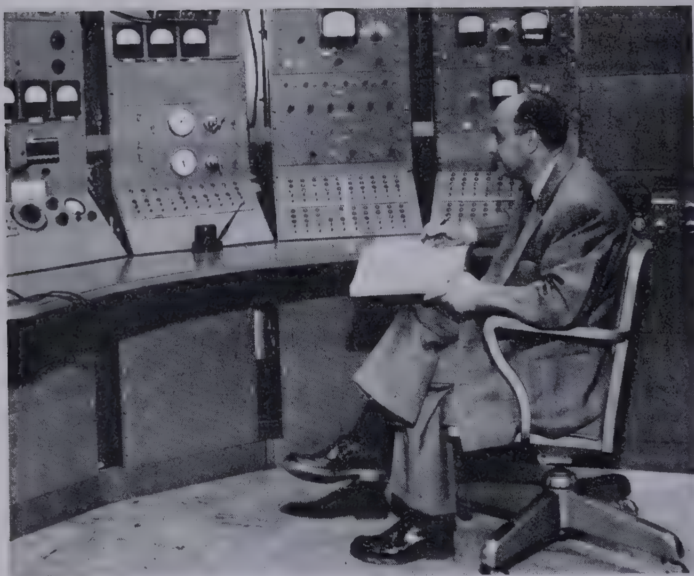
FIGURE 1 • 8. SCIENCE AND COMMUNICATION

(page 12)

The many kinds of animals, the different shapes of containers or tools, and the suggestion of a number system will generate many interpretations and deductions. That this is a record of the contents and offerings presented to an Egyptian prince when he was entombed probably won't be suggested by students—this is not as important as that they *try* to interpret the message.

To compare communication by the Egyptians to communication today, students may suggest that we still use pictures to convey ideas. But by using actual photographs or even live TV along with verbal descriptions in several languages, we are able to make communications much more available. TV transmission can be copied, preserved, and rerun to almost any point in the world—on instant demand.

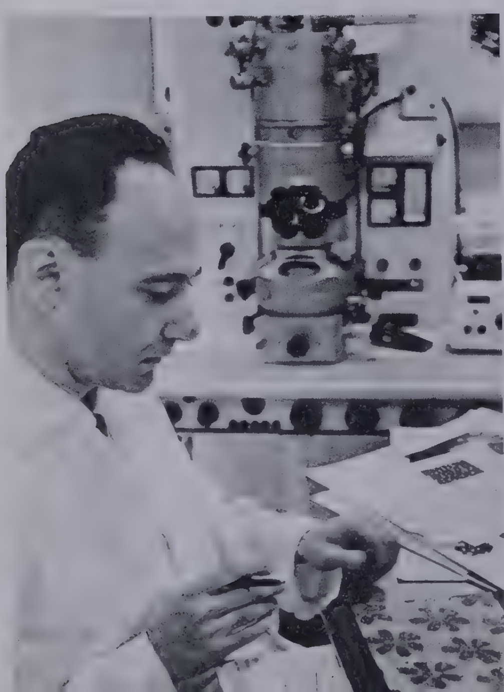
Science: An International Effort



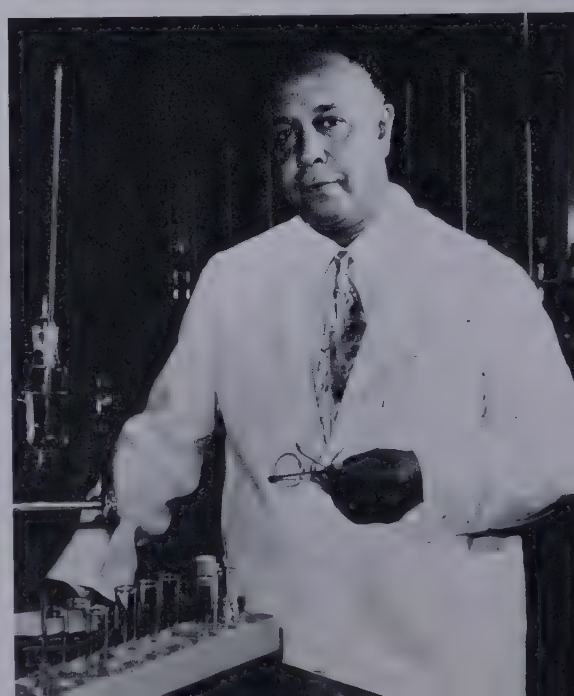
Enrico Fermi, an Italian, helped create the first atomic pile, at the University of Chicago.

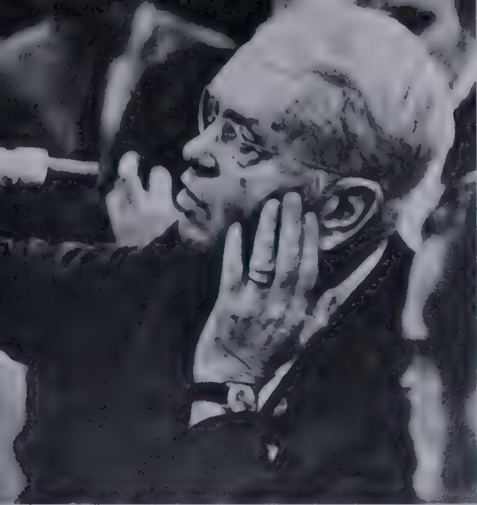
Figure 1 • 9.
Scientists of all races and many nationalities have worked to increase our understanding of matter and energy.

Humberto Fernandez-Moran, a Venezuelan biophysicist, greatly improved the electron microscope as a research tool.

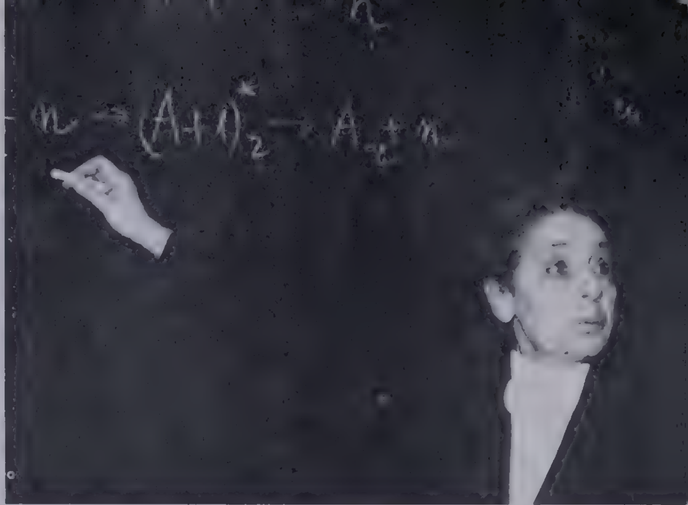


Percy Julian, a black American, has done much work in the chemistry of hormones.

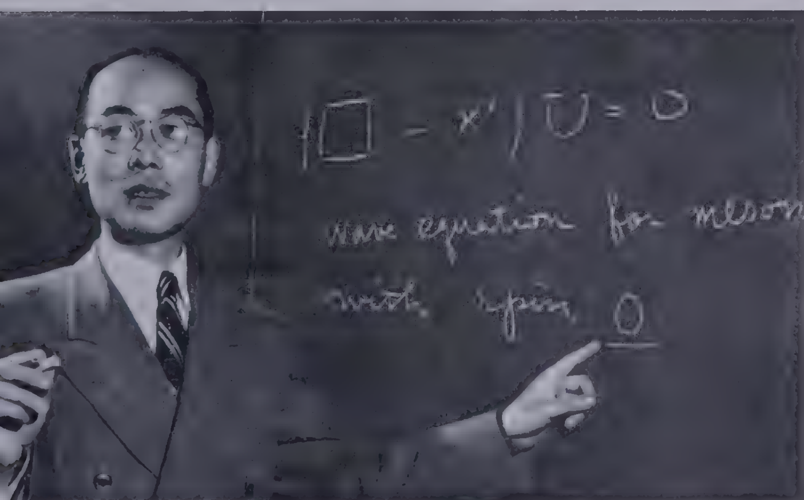




Harold Urey, an American chemist, discovered a heavy form of hydrogen. He has been active in studies of moon materials brought back by the Apollo missions.



Lise Meitner, an Austrian physicist, discovered the ninety-first element, *protactinium.* Her work in atomic physics was important in the later development of atomic power.



Hideki Yukawa, of Japan, predicted the existence of mesons, nuclear particles much heavier than electrons.

Tsung Dao Lee (*left*) and Chen Ning Yang, both born in China, are shown receiving the Nobel Prize for Physics. This work overturned an important theory called *the conservation of parity.*

First, science offers an opportunity for you to exercise your curiosity and to practice sound reasoning. Defining and working out a problem can be fun. And skills in doing so can be useful in all creative fields—in the arts, in business, in public service, to name a few. Second, science provides a view of the natural world that is necessary to every well-informed person. A citizen who lacks understanding of the basic processes and principles of science may find it difficult to make intelligent decisions about certain important issues that can affect his community or the entire nation. Flood control, conservation of wildlife, the exploration of space, pollution of air and water, research in medicine—these and a hundred other needs will call for the time, effort, and money of our society. And the voter will be asked, in many cases, to decide which problems are most important.

Today man has the power to shape the content and conditions of his surroundings. Science has provided a great deal of this power. But without support from well-informed citizens, the scientific community cannot continue its work. Without guidance from the public, science may fail to meet our most pressing needs. Finally, without a basic understanding of the methods and goals of science, the people of a nation may fail to use their resources wisely and to preserve the environment for themselves and for later generations.

PROBLEMS

1. Write a short statement which either supports or argues against each of the following ideas:
   a. Science began with cave paintings.
   b. The cave paintings in France and Spain are some of the earliest records of scientific activities.
   c. Science began with the use of tools.
   d. Science began with mathematics.
2. Suggest other uses prehistoric man may have had for his cave drawings.
3. Suggest some examples of investigations that might require the cooperative work of several branches of science.

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PROBLEMS

(pages 16–17)

These problems, and many of those that appear at the conclusion of other sections or investigations, may be assigned as homework or used as starting points for class discussion:

1. Students should realize that *none* of these statements can be accepted. Sound reasons for rejecting them should be included in the responses.
2. Students' suggestions might include the following:
   a. The drawings were used as decoration.
   b. The drawings were used for target practice.
   c. The drawings were used in rituals intended to bring good luck to the tribe in hunting.

The authors are not suggesting that prehistoric man was the originator of science. Since he left no written records, we have no basis for saying what he thought. However, the idea that prehistoric man recorded data, classified objects, described animals, and tested hypotheses is worthwhile for the students to consider.

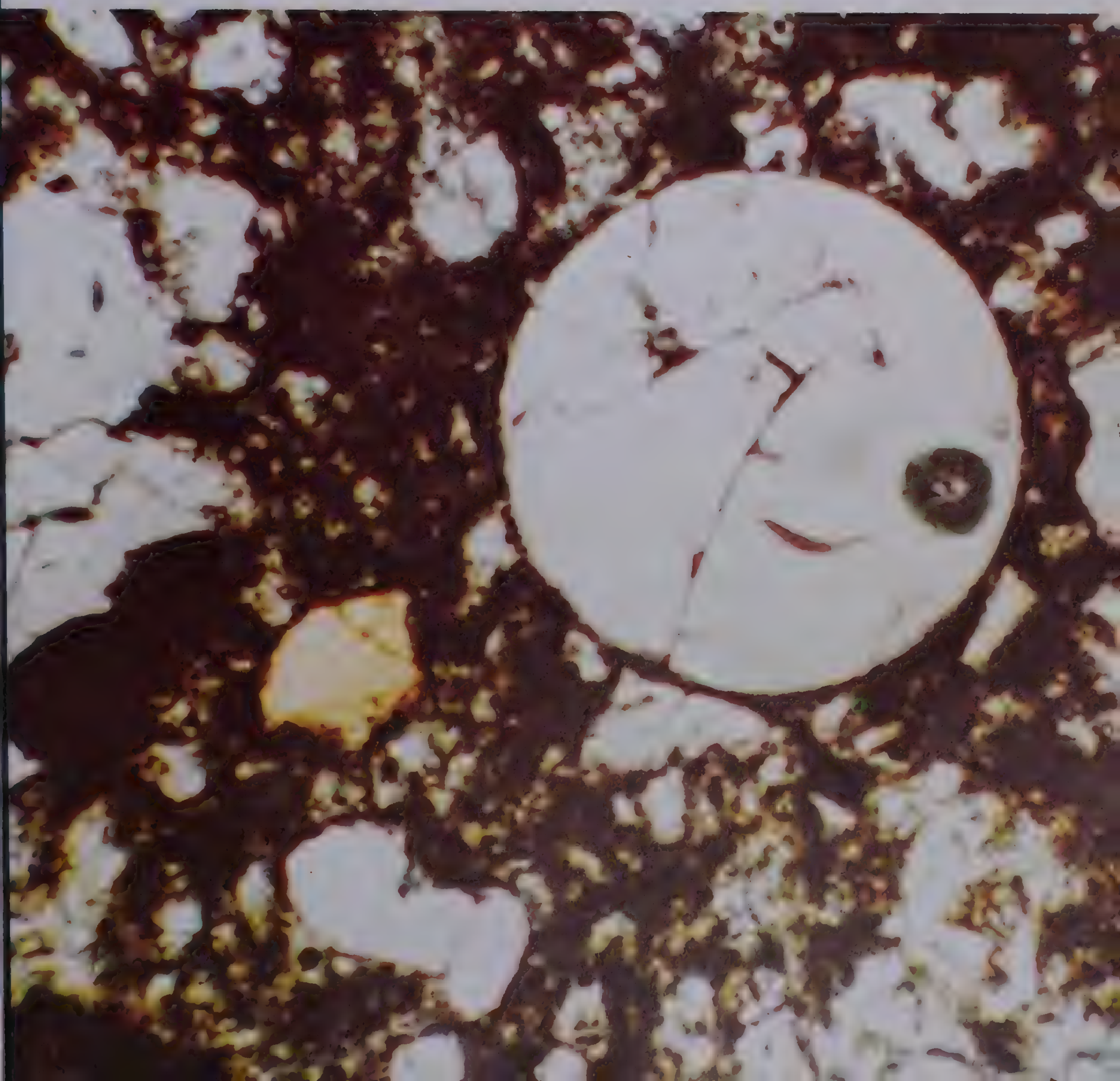
3. *a.* The search for a cure for cancer involves several branches of science including biology, chemistry, and physics (radiation effects).
   b. The success efforts to manufacture artificial organs to replace defective organs in the human body requires the work of technologists with considerable understanding of the biological and physical sciences.
   c. The success of attempts to make automobiles safer requires that scientists and engineers cooperate in their investigation of the causes of automobile accidents.

Students need to develop an awareness of the continuum that exists across the sciences. Most people have a tendency to divide science into discrete units. Yet it is apparent that science is not a series of separate entities and maximum progress depends on many scientists.

Reinforce the idea that scientific knowledge is not absolute and that our understanding of natural events must be modified as more is learned about our environment.

SECTION TWO

Structure of Matter: A Model



SECTION TWO

Structure of Matter: A Model

(pages 19–54)

Preview

The major thrust of Section Two is to make students aware of the processes of science—observation, investigation, interpretation, constructing models, and refining models as new evidence is discovered.

A brief definition of matter is followed by a condensed historical treatment of what some of the early philosophers—scientists like Democritus and Aristotle—thought about matter.

As an approach to an atomic-molecular-energy model for matter, an alternative model is presented—the demon (or gremlin) model. The behavior of matter can be explained on the basis of demons—tiny invisible fellows whose actions are responsible for everything that happens. This alternative model continues through Section Eight, where a demon model is no longer acceptable and the present atomic-molecular-energy model becomes the most plausible. Reports from teachers who have used the first edition indicate that students enjoy this comparison of models and that it assists them in reaching an understanding of the meaning of a scientific model—a major objective of the IME program.

There is considerable emphasis on the usefulness and limitations of models as used in science. Students see the importance of observation and interpretation as part of model building. They should learn that absolute certainty is never likely to be achieved.

In Section Two students attempt to answer various questions about the structure and behavior of matter. The investigations include: learning to estimate size of small particles and establish an upper limit to the size of atoms, studying the behavior of a soap film, investigating bubbles, drops and films (surface tension), the motion of particles, and separating components of matter.

Section Two also includes several "On Your Own" investigations. These are generally unstructured. The student designs and carries

them out, using individual ingenuity and skill and knowledge gained from previous work. Naturally, too much help from the teacher will destroy the intent of the investigations.

The section ends with a brief review of what has been studied so far and an introduction to Section Three.

Section Two opens with a photo of a thin section of moon rock. The circular structure is from a sphere of colorless glass (imaginative students may note a resemblance to "the man in the moon" in the sphere). Working with extensive moon samples, scientists continue to refine and revise the model of the structure of matter.

PLANNING AHEAD

Check material lists for each demonstration and investigation to be sure you have the equipment and supplies on hand.

Inquiry Demonstration.	Homogenized whole milk is needed.
Investigation 2.2.	Soap solution must be prepared.
Investigation 2.3.	Soap solution must be prepared.
Investigation 2.4.	A dye spot must be placed on filter paper strip for each team.
Investigation 2.5.	An IKI solution and a starch suspension must be prepared.

LEARNING OBJECTIVES

Given the opportunity to inquire, to investigate, to interpret data, and to offer hypotheses about the activities in the section, most students should be able to—

- Explain the tentative nature of models;
- Describe some of the historical attempts to explain the nature and the behavior of matter;
- Manipulate and use simple laboratory apparatus (droppers, beakers, film frame, metric ruler, funnels, graduated cylinder);
- Estimate or calculate approximate sizes of small particles, using indirect means;
- Develop hypotheses to account for Brownian movement;
- Interpret observations of the nature and behavior of water drops;
- Explain the behavior of drops on a variety of surfaces;
- Explain the separation of components from mixtures;
- Be open to alternative explanations and models;
- Construct or reevaluate models as new evidence is collected;
- Explain the roles of observation and interpretation in the construction of models;
- Explain the roles of prediction, investigation, and interpretation in collection of information and model construction.

Matter may be defined as anything that takes up space and has weight. Our natural senses of sight, touch, hearing, taste, and smell provide us with evidence that matter exists—as mountains, oceans, clouds, cabbages, pigs, and so on. But our senses alone do not permit us to see how matter is constructed or to know how it behaves.

Man has wondered about the structure of matter for thousands of years. Until a few hundred years ago, he had to rely on his natural senses and on opinions to explain the structure and behavior of matter. Microscopes, telescopes, and most other kinds of scientific instruments did not exist. The idea of experimenting to seek answers to questions was not an accepted procedure. In spite of these limitations, man's curiosity caused him to observe, wonder about, and make interpretations about matter.

A Greek teacher, Democritus (470–400 B.C.), used the word *atom* to describe what he thought was the smallest unit of matter. There was, according to Democritus, empty space between atoms. They might differ in shape and size, but all atoms were made of the same kind of "stuff."

In the schools of Democritus' time, teachers and groups of students often walked about together, informally discussing problems, asking questions, and forming theories about the nature of man and the physical world. Imagine that while Democritus was walking with his students, he picked up a dried leaf, crushed it in his hand, and said, "This leaf is composed of many things. After I crush it, I am still holding pieces of the original leaf. If I crush it further, I will still be holding pieces of the leaf, even though they look and feel like dust. The smallest pieces are composed of particles so small we cannot see them. These I call atoms."

Democritus' ideas about atoms were almost lost to future generations because Aristotle (384–322 B.C.) rejected them. Aristotle, one of the greatest Greek writers and philosophers, adopted an older concept of matter, which assumed the existence of four elements: fire, water, earth, and air. These four, and various combinations of them, were thought to form all the different substances on earth and in the heavens.

Aristotle's influence lasted for many centuries, affecting European thought and society through medieval times. Though his writings represented a lifetime of observation, curiosity, and debate, they were accepted without much question by generations following. Few would have thought it proper to test Aristotle's assumptions and conclusions about matter and the physical world.

A great revolution in science occurred when experimental *testing* became the accepted procedure. Today, we expect evidence. No scientist can set himself up as an authority without showing that his ideas are supported by tests—experimental tests that can be repeated by other scientists and that will produce the same results.

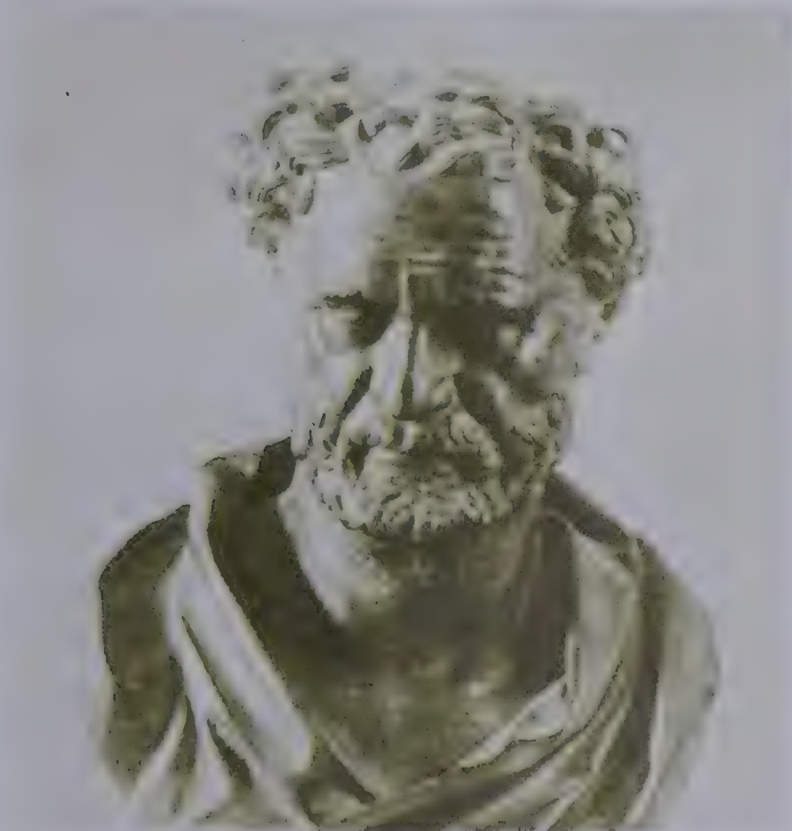


Figure 2 • 1.
Democritus.

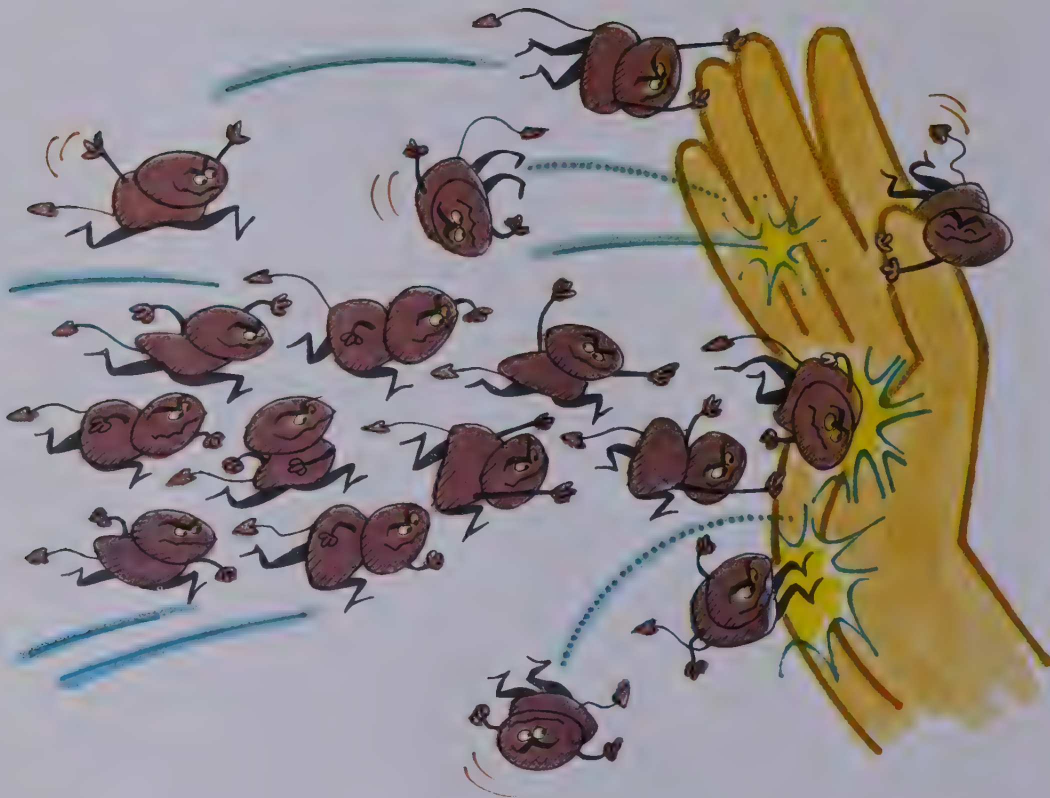


Figure 2 • 2. A possible explanation for pressure against a moving hand.

Although the word *atom* is useful today in talking about the structure of matter, no one has ever seen atoms. Throughout the past century, the idea that matter might exist as tiny particles was based upon some evidence and many assumptions. As additional experimental evidence was uncovered from the tests of the particle theory, some of the assumptions were verified. Today scientists have many kinds of evidence to support the theory. They interpret the data and the remaining assumptions to indicate that matter is made up of the tiny particles we call *atoms*.

We could assume, however, that all of the properties of matter arise, not from the structure of atoms, but from other causes. We could interpret the evidence and assumptions to mean that the properties and behavior of matter are due to the activities of

small demons.[1] We would then have two theories, and either one might be used to explain the behavior of matter. The *atomic theory* can be used to seek an explanation for the behavior of matter in matter itself. The *demon theory* can be used to explain this behavior on the basis of something acting on matter from the outside.

The terms *demon* or *gremlin* can be useful in understanding the nature of science. For example, if you put your hand out the window of a rapidly moving automobile, a force pushes your hand backwards. What is this force? It *could* be caused by thousands of invisible demons pushing against your hand (Figure 2·2). If the car stops, you no longer feel the force. Perhaps demons push only against something that is moving.

You probably would not agree that this force is caused by demons. You might say your hand is forced backwards because it is pushing against air and that air is the force—not demons. But so far the evidence could be used to support both theories. You have little reason to reject either one.

The idea of demons (or any alternative) can be useful. Think of demons as being responsible for a certain event and attempt to find evidence that supports this explanation. Then see if the same evidence can be used to support a different theory.

This method will be used a number of times throughout the course. You will be asked to interpret an observation in terms of demons or some other cause. Then you should select the explanation that is best supported by evidence gathered from your investigations. Seeking the best explanation for something you observe is an important part of science.

You are not being asked to believe in the existence of the demons described in this book. You should realize, however, that words like *atom*, *molecule*, or *demon* do not *explain* anything. Therefore you will be asked to tell what atoms must be like if they are used to explain the behavior of matter. You also will be asked to explain the same behavior by describing the powers demons must have if they are the cause of this behavior.

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[1] You may prefer to use a different name, such as *gremlin*.

Figure 2 • 3. Could the effects shown here be explained in terms of demons? If so, would the demon model used to explain Figure 2 • 2 need to be changed? In what way?

Observation and Interpretation

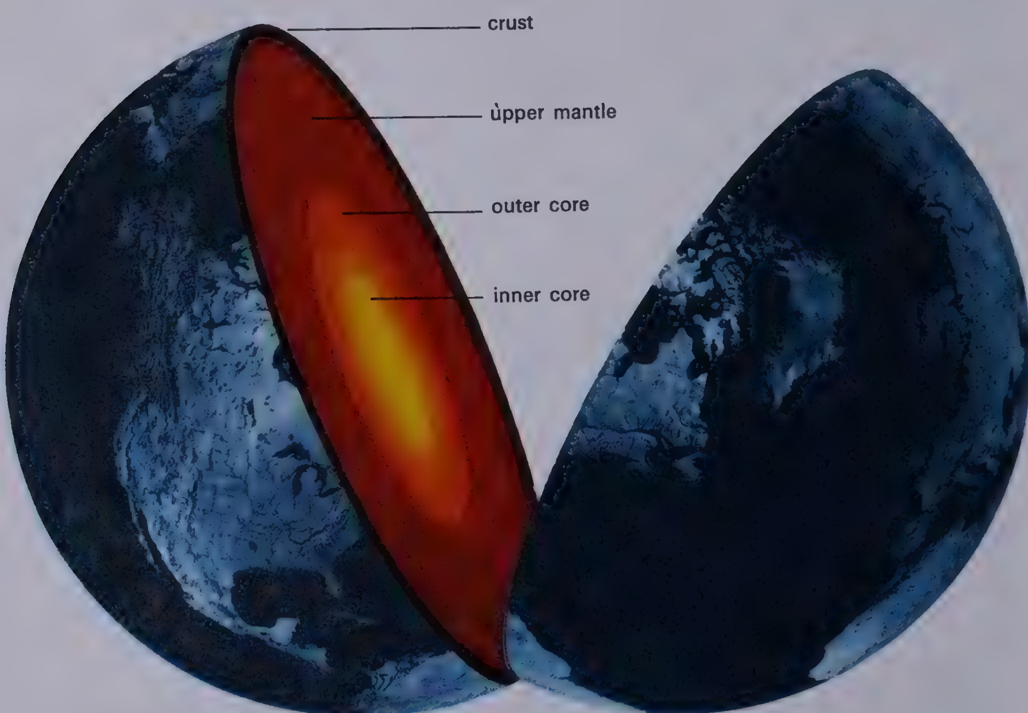
When a scientist says that something is *true*, he usually means that available evidence supports a *model* he has constructed. The model makes it possible for him to relate certain observations, experimental results, and data to one another. Scientists use the term *model* in a much different sense than most of us do in ordinary speech. We talk about model airplanes, model behavior, or fashion models. None of these fits the idea of a scientific model very well. The kind of model the scientist uses is a *mental image*. It may be based partly on past evidence and accepted facts; it may be based partly on theories; and it may be based partly on opinions, guesses, or hunches. If possible, a scientist will want to construct a physical, visible copy of the model he has in his mind, and this may make it easier for him to communicate his ideas to others. But the model in his mind may be too complicated to construct. For example, imagine trying to construct a complete model of the universe, which includes billions of stars. Or the mental model might be based on a process that extends over great lengths of time—the evolution of mammals, for example. Perhaps speeds, distances, and temperatures involved in the model cannot be created or copied in a physical model. In any case, the model, whether it can be copied or not, exists in the mind of the scientist.

How are models useful? Many scientific models allow man to organize past and present experimental results into a logical pattern. A good model fits together all the available evidence. Then, if someone finds new evidence that does not fit the model, the model must be changed—or perhaps even discarded in favor of another model. Consider again a model designed to show the structure of the universe—one that includes all that is known or suspected about the number, size, and movement of stars and planets. According to this model, it is supposed that there are many planetary systems throughout the universe. Each system has a star, or "sun," as its center; and each sun may have planets orbiting around it. In our part of the universe, there are millions of stars, or suns. Telescopes show that this model appears to be true for our own solar system, but we can only *assume* that it is true

for distant regions of the vast universe, where planets, moons, or suns cannot yet be observed or detected. Thus, our model may change as we develop new ways of exploring, observing, or *thinking* about the universe.

Consider our own planet. Geologists have constructed several models to help us visualize what the structure of the earth may be like. Though no one has yet observed what lies beneath the very thin crust of our planet, geologists use drawings of models to show what they think the interior of the earth is like (Figure 2•4).

Figure 2 • 4. A model of the earth's structure.



Other examples of scientific models may be found in biology—the study of living things. Biologists use a model to explain how certain traits are passed from parent to offspring. With this model they are able to make useful predictions, even though the actual process represented by the model occurs on such a small scale that it cannot be seen.

On the other hand, something is not easy to understand just because it is easy to observe. We might find models helpful in seeking explanations for visible but unfamiliar events. Suppose you observe an animal of a kind you have never before seen, stealthily moving across a grassy field. You might explain its behavior by saying that the animal is hungry. Actually you have no way of knowing what the feelings of the animal are. You use your own familiar feeling of hunger as a model to explain the actions of the animal. Your explanation might be called the *hunger model* for this animal's behavior.

A different explanation for the behavior might be a *fear model,* based on the assumption that the animal is attempting to find a place to hide—perhaps from hunters, perhaps from other animals. The hunger model predicts that the animal's behavior would change if it found food. The fear model predicts that the animal's behavior would change if it reached some bushes or a dense wood. Both models allow you to make predictions. And through further observations you might decide which seems to best explain the animal's behavior. And you could still be wrong.

Perhaps we should look at one more example before turning to atoms and molecules again. Imagine a boy living in a small valley near the ocean. Until he has traveled out of the valley, his model of the world might resemble a large bowl. If he moved up to the ridge, he might get the idea that the earth is like a plate with some uneven places in it, but extending out in all directions and on the whole rather flat. If he moved down to the seashore and watched ships sail away, he might change his model again, so that it resembled a bowl turned upside down. In this way he could explain the gradual disappearance of the ships. If he saw pictures of the earth taken from a rocket, he might change his model of the earth to resemble a ball.

Figure 2 • 5. The curvature of the earth is clearly seen in this view taken from the *Apollo 17* spacecraft during the final lunar landing mission in the Apollo program. Africa, the Arabian Peninsula, and the island of Madagascar can be clearly seen. The south polar ice cap is also visible. Does this evidence change the model proposed in Figure 2 • 4?

As you continue, keep in mind that a model is a mental picture of what something is supposed to be like. And if the model is scientific, it must be revised when it is not in agreement with all evidence. A model in science is a mental device that allows us to organize observations and experimental results into a useful pattern. Notice that we say *useful*. Such a model must also be consistent—that is, it must allow us to fit all evidence together logically. This does not mean the model is truth in the sense that it is a fact or something that can be observed. If observation or

experiments do not support a model, the model may be changed or replaced by one that better agrees with the observations and experimental evidence.

While it is reasonable to assume that matter is made of particles called *atoms*, you do not have any way of knowing what the shape of an atom might be. Lacking evidence, why not choose a simple and convenient model—a circle (Figure 2 • 6*A*)? Two or more atoms joined together form what is called a *molecule* (Figures 2 • 6*B*, *C*, *D*). Atoms may combine to form large molecules

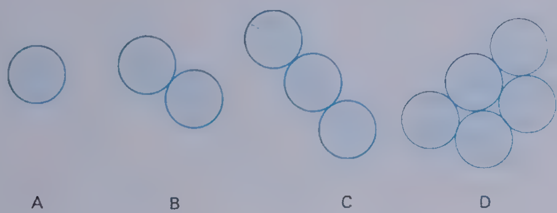


Figure 2 • 6. (*A*) Model of an atom. (*B*,*C*,*D*,) Models of molecules.

(Figures 2 • 7*A*, *B*). On the other hand, large molecules may be broken apart to form smaller molecules or individual atoms.

It is not as easy to draw a model representing energy. But we can use a *word* model: *Whenever some kind of activity is taking place, energy is present.*

The purpose of the investigations you are about to perform is to allow you to make some observations about the behavior of matter. You will be asked to gather the observations, organize them, interpret them, and from this information, build a model that will help you in understanding the structure and behavior of matter.

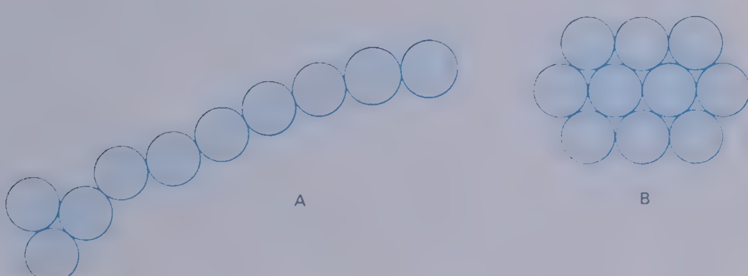


Figure 2 • 7. Atoms in larger molecules may be arranged in chains (*A*) or clusters (*B*).

During your investigations, it is important that you make a clear distinction between what you see (observation) and the meaning you draw from it (interpretation). Your observation of the movement of the sun relative to the earth is the same as the observations made by men hundreds of years ago. Yet you believe the earth moves around the sun, while they believed that the sun moves around the earth. See Figures 2 • 8 and 2 • 9 for drawings of the ancient and modern models of the solar system.

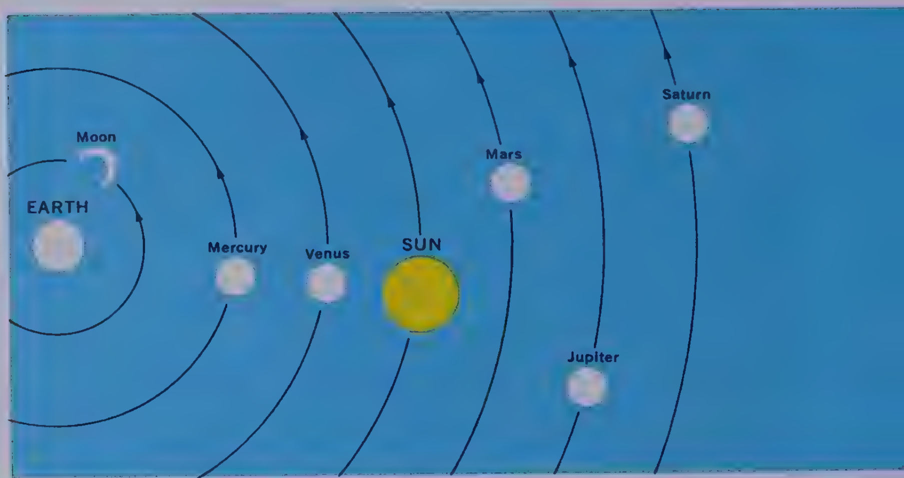


Figure 2 • 8. This relationship of the earth to the sun, the moon, and all known planets was widely accepted for more than a thousand years after it appeared in 150 A.D.

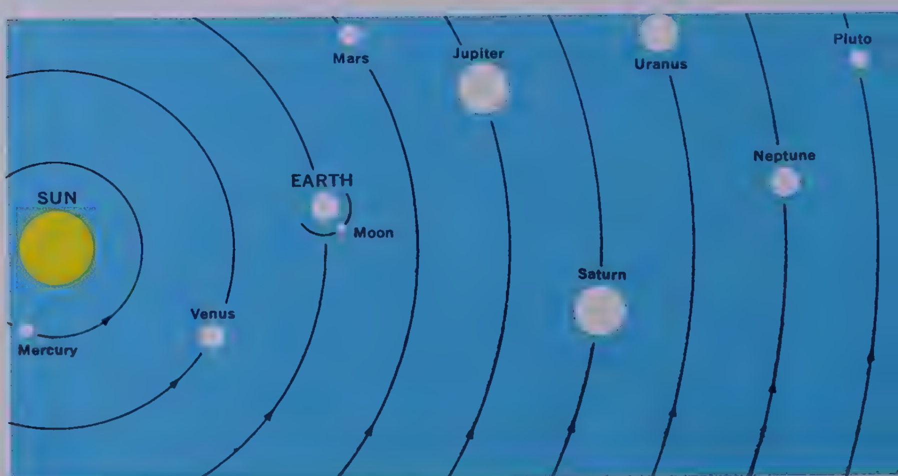


Figure 2 • 9. A modern model of the solar system. Compare this model with Figure 2 • 8. Sizes and distances are not to scale.

FOR CLASS DISCUSSION

1. It is often difficult to decide whether a *fact* is based on observation or on interpretation. For example, highway police often check for speed violations by laying a "detector wire" across the road. Instruments attached to the wire record the impact of each vehicle's front wheels and rear wheels as they cross the wire. The time elapsed between front- and rear-wheel impacts is then indicated. Whenever the time elapsed is less than a certain interval, it is accepted as fact that the vehicle is speeding. Is such a *fact* based on observation or interpretation? Give reasons for your answer.
2. What is your opinion of each of the following statements?
   a. It is quite proper to honor the opinions of those who have studied a subject thoroughly. But it is not reasonable to accept, without question or doubt, statements of fact as representing absolute truth.
   b. It is important to distinguish between intelligent doubt —which may deserve investigation—and a demand for *proof* in every case. For instance, it is reasonable to accept as fact that if a person steps in front of a speeding automobile, he will be badly injured or killed.
   c. Seeing is believing.
3. What kind of model do you think Democritus might have used to describe atoms?

Structure of Matter: A Model

(pages 20–31)

Students should begin to see the role of a model in science and realize that a model is not necessarily something we believe to be true; rather, it is a device we employ for convenience, to correlate and explain observations and experimental data. With a scientific model we can organize (or reorganize) results that may seem unrelated, contradictory, or unexplainable. Finally, and significantly, a scientific model encourages the generation of new ideas—ideas that could not be directly inferred from the facts or assumptions used to build the model.

If you present the existence of atoms and molecules as fact, students may have difficulty in thinking critically about present concepts of the behavior of matter. They may accept the concepts as "laws" rather than as models subject to further testing. If students are tempted to regard present ideas as facts, remind them that our concepts of atoms and molecules have changed radically and often in the last century—and are still changing. A few decades ago scientists believed that salt crystals were made up of molecules and that ions were formed only when crystals were dissolved in a solvent. Today we think that many crystals are made up of ions rather than atoms or molecules.

Not long ago the most widely accepted model of an atom was that of an indestructible and unchangeable entity. Today we "know" that particles may be added to, or knocked out of, the nuclei of atoms and that atomic nuclei may be split into many particles.

The demon hypothesis is presented as a means of encouraging students to set up alternate hypotheses or models and to help them see that "naming the baby" does not explain where the baby came from or how he lives. To put it another way, a model is something we impose on nature—not something in nature.

At this point it might be well to ask students to try suggesting examples of scientific models—other than those described in the text. It is not possible to predict what suggestions students may offer. Encourage them to offer ideas of scientific models and to discuss examples critically without fear of ridicule from other students.

Concerning Figure 2 • 3, students should be given wide latitude in answering the questions. Some students may wish to explain what is happening in terms of demons. Others may simply say it is caused by wind. The demon model in Figure 2 • 2 need not be changed, as demons could be pushing against the trees and water. Some students may argue that if demons only act against something that moves, then the

demon model may need changing. Still another answer could be that there are two kinds of demons pushing on opposite sides of the trees and water.

FOR CLASS DISCUSSION

1. A trial for a traffic violation provides the basis for this problem. The defendant claimed he was not speeding, and he pointed out that time is only *one* of two factors needed to measure speed—distance is the other. The police calculation of speed was based on the distance between the front and rear wheels of a "standard" size car. But the distance between the front and back wheels of the defendant's small foreign car was shorter. In the time interval measured, the defendant had traveled a shorter distance than the police assumed. Revised calculation showed that he was not guilty of speeding. And the "fact" (that he was speeding), based upon *interpretation,* turned out not to be a fact at all.
2. *a.* Most students will agree that this is a reasonable statement.
   b. This example is intended to guide the students toward caution in investigating statements of fact. A safe laboratory program depends upon caution, good sense, and attention to directions.
   c. This statement deserves serious student criticism. There is no question that what actually occurs should be believed. But too often it is an incorrect *interpretation* of an observation that is believed instead of what really happened.
3. We cannot be sure how Democritus visualized the structure of atoms. Students may suggest that atoms are of different shapes, to explain the behavior of different kinds of matter. For example, atoms of oil could be round, atoms of rock might have an irregular shape, and so forth.

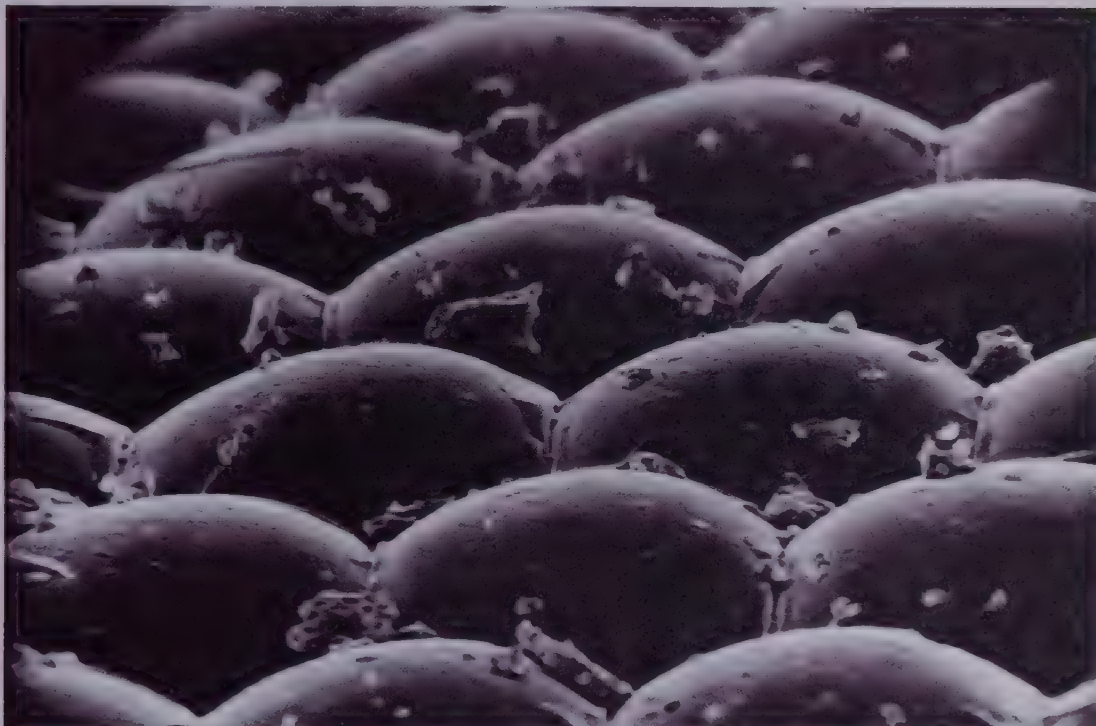
Though its average distance from the earth is about 900,000,000 miles, the planet Saturn and the satellite rings surrounding it can be greatly magnified with modern telescopes, making photographs like this possible.

Like the electron microscope, the telescope allows people to view objects and events far beyond the range of the naked eye.

Observing How Matter Behaves

Figure 2 • 10. The two instruments shown, the electron microscope and the telescope, help scientists gather descriptions and information on the behavior of matter far beyond the range of the human eye. Such observation and experimental evidence help the scientist to develop a model of matter that is consistent—from molecules to planets and stars.

A view of a fly's eye taken through the electron scanning microscope, at a magnification of about 3500 times. The small particles on the eye lenses are dust and matter that settled out of the air while the eye was being prepared for study.



The electron scanning microscope enables scientists to see very small particles, structures, and organisms.

The Behavior of Matter

The atomic-molecular model used by scientists to explain the structure and behavior of matter is based on some of the same observations, investigations, and interpretations that you will make. The incredibly small, invisible world of atomic particles presents a difficult problem because we cannot get at it or even see it. We have the same problem, of course, with seeing and understanding what occurs in distant parts of the universe, which are beyond the reach of our most powerful telescopes and the fastest spaceships now imagined. For this reason a useful model of the structure of matter is necessary. We cannot see atoms or molecules. Yet we must find some way to account for the appearance and behavior of matter. Let us begin the same way a scientist might—by observing and investigating matter.

Figure 2 • 11. A model: the "black box" explanation. Scientists are often faced with the problem of explaining something that is caused by hidden mechanisms. Can you imagine what must be going on behind the door of the vending machine? What causes it to behave as it does? Your explanation must account for all of the actions seen. As in science, you may find it nearly impossible to *verify* a reasonable model about the behavior occurring in a "black box."

INVESTIGATION 2.1: Estimating Size

The purpose of this investigation is to provide information that may be useful in making a rough estimate of the size of atoms and the size of demons (if they exist). You will observe some very small pieces of matter. Remember that *looking* at small particles is observation; but *saying* that atoms or demons must be a certain size is interpretation.

MATERIALS (per team)

Chalk
Plastic ruler, metric/English
Hand lens

PROCEDURES

A. Find the thickness of one sheet in your book. There are at least two methods you might use. One is much easier *and* more accurate than the other. Try both methods and record the data in your notebook.

B. Crush a piece of chalk into fine particles. Place the ruler alongside the crushed chalk and view the particles and the ruler through your hand lens. Attempt to measure the size of the smallest particles of chalk you can see.

INTERPRETATIONS

1. Which did you find easier to measure—the thickness of a piece of paper or the size of a particle of chalk?
2. From the measurements of paper and chalk, make a general statement about your best estimate of the size of atoms or molecules.

The Behavior of Matter

(page 34)

If students have trouble grasping the idea of a model, review with them the materials relating to models beginning on page 25. Throughout the course we continue to build toward an atomic-molecular model as an aid to understanding the structure and behavior of matter.

INVESTIGATION 2.1: Estimating Size

(page 35)

Of course it is not possible for students to determine the exact size of atomic particles. After estimating the size of the smallest particles they can see, students should be able to state that both atoms and molecules must be even smaller. Thus they will have at least established an upper limit for the size of such particles.

MATERIALS

The ruler should be calibrated in both metric and English units.

PROCEDURES

A. Unless a fine caliper or a paper gauge is available, the simplest way to determine the thickness of a single sheet is to measure the thickness of the book and divide by the number of *sheets.* (Some students may divide their measurement by the number that appears on the last page of the book. See whether they can correct this error themselves.)

Several students may try to measure the thickness of a single sheet directly with a ruler. One of the major purposes of this investigation is to illustrate the difficulty inherent in measuring very small distances. For easy calculation have students measure a hundred sheets instead of the whole book. It may be necessary to review some basic arithmetic before they make this calculation. For relatively thin paper, the following information is typical:

Thickness of 100 sheets = 0.78 cm, or 0.3 inch

Thickness of 1 sheet = 0.78/100 = 0.0078 cm, or 0.003 inch

B. Take care to prevent chalk dust from blowing about the room. The smallest piece of chalk is too small to be measured accurately with any instrument a student is likely to use. He should estimate the size to be far less than 1/10 of a millimeter. Typical estimates are 0.0015 inch, or 0.004 cm. Stress that we can never obtain exact measurements—only estimates that have different degrees of accuracy.

INTERPRETATIONS

1. It is relatively easy to obtain the average thickness of sheets of paper piled in a stack. This would be very difficult to do with particles of chalk.
2. Both atoms and molecules must be smaller than the smallest piece of chalk observable. Some students may express this quantitatively. For example: "An atom must be smaller than 0.004 cm."

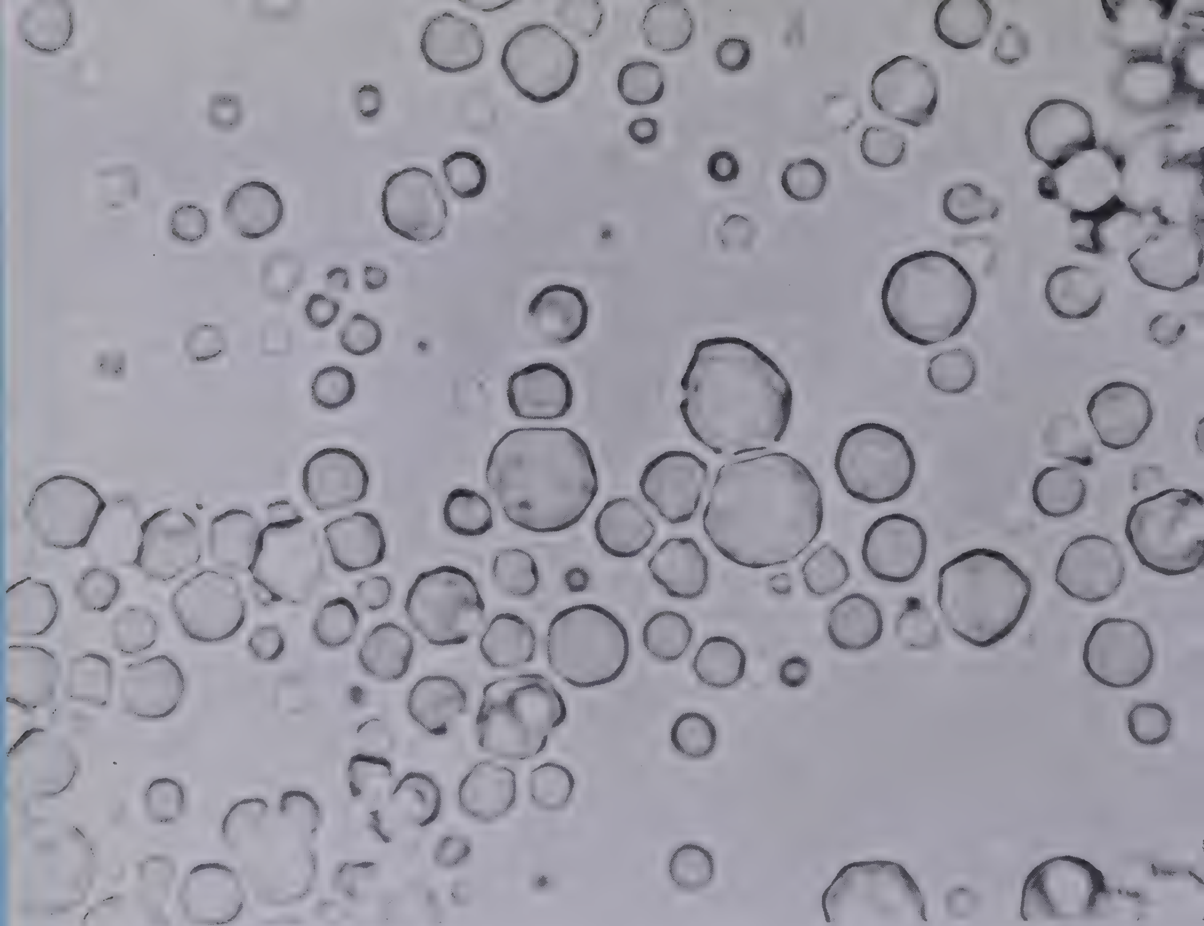


Figure 2 • 12. This photomicrograph shows fat particles in milk magnified approximately 1300 times.

Motion of Particles

Your observations indicate that if matter is made up of small units, or atoms, these units must be smaller than the smallest pieces of chalk—so small that they cannot be directly observed. Other ideas about the nature of matter can be explored. Two major directions for our research are evident: one involves a study of the *structure* of small particles; the other involves a study of the *behavior* of these particles.

If you place a drop of homogenized milk (diluted 1 part milk to 3 parts water) on a glass slide and examine it under the high power of a microscope (400X or more) in strong light, you should

Figure 2 • 13. The presence of demons could be an explanation for the motion of particles.

see tiny particles. If you look closely, the particles can be seen to move about in random, jerky motions, as though each particle had its own source of energy.

The continuous motion of these particles could be the actions of demons. You would have to assume that demons are smaller than the particles or that demons are as transparent as the water—for the demons are not seen. Also there would have to be many demons present, each pushing or pulling on a particle to keep it continuously in motion. All observations indicate that the random, jerky motion of particles continues indefinitely; therefore, demons must have an endless source of energy! Or perhaps it is possible that demons are able to obtain their energy from the light shining upon them.

In fact, you are likely to suspect that something other than demons accounts for the continuous motion of the particles. But can you back up your idea with evidence?

PROBLEM

Try to describe models that could account for the continuous motion of the particles. Develop two arguments: one crediting demons with this activity, the other explaining the behavior of the particles in terms of the properties of atoms. Be as convincing and consistent as you can in developing both of these models.

Motion of Particles

(page 36)

If a microscope is available, give students an opportunity to observe Brownian motion. This could be scheduled at the same time they are completing Investigation 2.1.

INQUIRY DEMONSTRATION: Observing Brownian Motion

(Teacher Only)

MATERIALS AND EQUIPMENT (per class)

Microscope with 40X objective and 10X eyepiece
Microscope light
Microscope slide and cover glass
Homogenized whole milk suspension. (Ten ml of milk in 30 ml of water is a suspension of sufficient particle density for observation. Other liquids that have proven satisfactory are suspensions of Carmine red and other dyes that are not water soluble. The addition of small amounts of Congo red or Sudan III to the milk may make the particles easier to see. Some teachers report good results with a small amount of carbon black added to the milk.)

PROCEDURE

Place a drop of the suspension on the slide and place a cover glass on top. Observe under high power.

The movement results from the impact of water molecules on the butterfat particles. If matter were a uniform continuum, there would be no net forces acting on the particles, so they would be stationary. Only by assuming that matter is varied, discontinuous, and made of discrete particles and that these particles move about at random can we logically account for the motion of the butterfat particles.

At this point the atomic-molecular model should not receive undue emphasis. The alternative explanation (demons) for the behavior of matter has a strong appeal, primarily because it seems simpler. As students have more experience in analyzing the behavior of matter, they will observe regularities that increasingly restrict the behavior of

demons. More assumptions limiting the demons' habits and abilities will be necessary. The demon model must come to resemble more and more closely the model of atoms. Then the choice is reduced to one of *terms*, not real differences. Conversion to the atomic theory will be more lasting and knowledgeable if students begin to see the increasing similarity between the assumptions needed to support the demon model and the demonstrable conclusions that are built into the atomic-molecular model. When the two models become quite alike in nature—as well as equally complex—the choice is reduced to one of terminology.

Words alone do not explain anything. Brownian motion is no more explained by the words *atom* or *molecule* than by the word *demon*. It is the association of evidence and logic with words that makes one choice preferable. For example, after a bit of rehearsal or a homework reading assignment, a student's answer to the question Why do plants bend toward the light? might be *phototropism*. If asked for a definition of phototropism, he is likely to say, "The bending of a plant toward the light." This makes a neat (but rather worthless) circle. Although there is nothing wrong with either response, neither answer provides any explanation of why the plants bend.

PROBLEM

If students assume that demons exist, it is relatively easy to explain the motion of the particles. The demons simply push and pull on the particles as fancy strikes them. They must be invisible, and presumably they could gain their energy of motion from the light that falls upon the microscope slide. Some students should be able to suggest that the latter idea might be tested if the particles could be observed in reduced light.

The atomic-molecular model is more complex and involves the statistics of probability. It assumes that atoms and molecules are in constant motion. The particles (water molecules) that strike the butterfat particles are too small to be seen and are moving at various speeds. They are so small that many of them may strike a butterfat particle in a small fraction of a second. On the average, one side of a particle is as likely to be struck as another, but at any instant in time the probability that all sides will be struck with equal force is slight. Most particles tend to remain rather close to the point where they are first seen. But their motion is jerky, because the water molecules striking them move at different speeds and in different directions.

Any other explanations that students derive (as long as they are logical and related to the observation of Brownian motion) should be treated as credible, whether the explanation involves demons, atoms, or some other agent.

Bubbles, Drops, and Films

Usually there is air both on the inside and on the outside of a soap bubble. The bubble itself is a very thin layer of liquid—a film. A soap bubble is a spherical film of water and some dissolved soap.

A *drop* of liquid may be surrounded by air (or other gases), but its interior is all liquid. A drop of one liquid may be surrounded by another liquid, such as an oil drop in water.

Bubbles are fun to make and look at, but they also play a vital role in much more serious events and processes. Let us look at a few examples related to science and technology. An air bubble in the bloodstream can block the flow of blood, which could result in injury or even death. Bubbles formed during the manufacture of steel could result in a weak beam in a bridge or a faulty valve in a rocket engine.

The structure and behavior of drops, films, and bubbles may be described with a model that illustrates the structure and behavior of matter. Or you can assume that demons are responsible for the characteristics and activities of the matter in drops, films, and bubbles.

You have gathered information about the size and motion of some of the smallest particles of matter that can be seen. Now you will investigate the behavior of water particles. With the information gained from the investigations, attempt to construct a model to explain this behavior. Your work in later investigations should provide additional information which may increase your confidence in the model or which may cause you to change it.

INVESTIGATION 2.2: The Nature of Drops

You are developing a model for matter. In this investigation you try to discover some of the properties of matter which you can explain, using the structure of atoms or using demons.

MATERIALS (per team)

Medicine droppers, 2
Wax paper or plastic sheeting such as Saran Wrap or Baggies (about 4 x 8 inches)
Toothpicks, 4
Soap solution
Hand lens
30 ml of oil (vegetable, mineral, petroleum, or silicon)
Beakers (250 ml) or jars, 2
Paper towels

PROCEDURES

A. With a clean dropper, place several water droplets of different sizes on the wax paper. One droplet should be as small as possible, and the largest should be many times that size. Place variously sized droplets on other surfaces, such as a piece of plastic sheeting, a tabletop, and a piece of paper towel.
B. Predict what a side view of the drops will look like on each surface. What will be the shape of the drops?
C. Observe differences in the shapes of the drops, beginning with the smallest. Make sketches and record your observations.
D. Place two small drops of water on the plastic sheeting as close to each other as possible. Determine how close the two drops must be to each other before they interact. Record this interaction. What happens to the two drops when they touch?
E. Carefully touch some of the droplets with the tip of a clean toothpick. Examine with a hand lens. Can you touch the drop lightly enough to cause a dent in the water? Observe and record any change in appearance of the drops.
F. Predict what will happen if you dip the tip of a clean toothpick into the soap solution and then touch a water drop with this toothpick. Repeat this procedure several times with other drops. Record your observations in your notebook. Did you obtain the same results as in Procedure D?

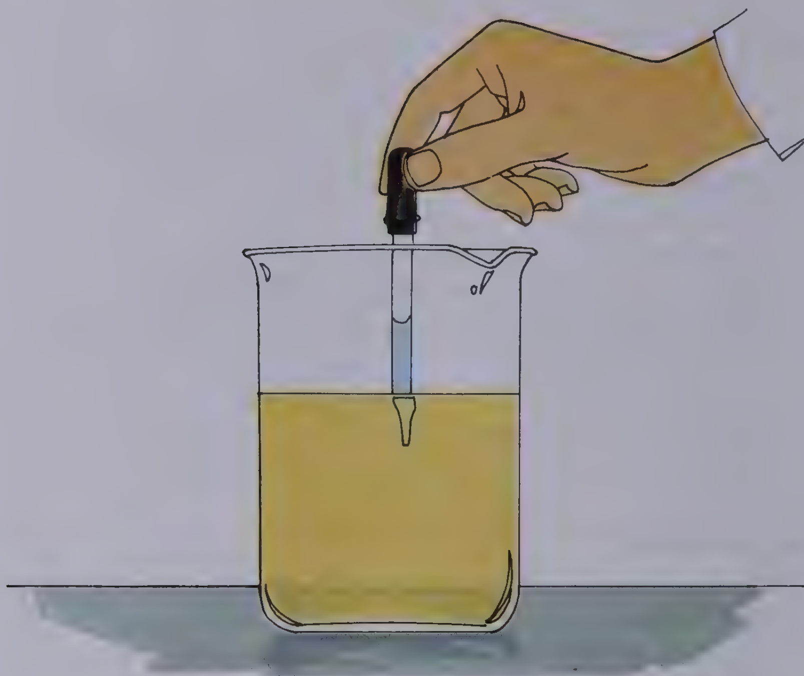


Figure 2 • 14. Setup for Procedure G.

G. Carefully introduce a few drops of water into a beaker about ⅔ full of a clear oil, as shown in Figure 2 • 14. Describe the shape of these drops. Can you explain why they have this shape? What happens to these drops? Slowly squeeze the dropper until all the water has been forced into the vegetable oil. Do all the drops move at the same speed? Record your observations.

H. Follow the steps in Procedure G again, but this time use a dropper full of clear oil and a beaker of water. Describe and explain the results.

INTERPRETATIONS

The following questions may serve as guides in making interpretations, but do not feel limited by them. The value of this activity will depend on your ability to change, if necessary, the model you have developed to describe the behavior of water particles. The only requirement is that you support your statements with experimental evidence.

1. Why do you think drops take the shapes you observed?
2. What could make the shape of drops change with increasing size?
3. Does the material or surface on which a droplet is placed affect the droplet in any way? If you found that different surfaces have different effects, try to explain the result in each case.
4. What statement can you make about the behavior of two water drops when they touch?
5. How did the shape of the droplets change when touched with a clean toothpick? With a toothpick dipped into the soap solution? Explain your answers.
6. Do you think that water is attracted or repelled by wax? Design an experiment to test your answer.
7. Copy Figure 2 • 15 in your notebook and complete the explanations to the best of your ability. Make up rules about how demons behave, to explain your observations of the behavior of drops. Also try to imagine properties of matter that would explain this behavior.

Behavior to Be Explained	*Possible Explanation Using the Demon Model*	*Possible Explanation Using a Structure-of-Matter Model*
The difference in shape between large and small drops of water on wax paper.		
The effect of soap on a water drop.		
The behavior of two water drops when they touch.		
The shape of a water drop when it is in oil.		
The shape of a drop of oil when it is in water.		

Figure 2 • 15.

Bubbles, Drops, and Films

(page 38)

A study of bubbles and films involves the phenomenon of *surface tension*. This property of liquids is encountered in many ways, yet it is understood by relatively few people. If water is sprayed on the waxed surface of an automobile, drops of various sizes form; but on an unwaxed painted surface, water may spread into a film. Detergents decrease the surface tension of water so that the water particles are free to penetrate minute pores in clothes or dishes. For this reason detergents are often called *wetting agents*.

In Investigation 2.3, water will not form a film on the wire frames unless the attraction between molecules is reduced. The addition of soap or detergent molecules decreases the attraction of water molecules for one another and allows a thin film to form. The contraction and resilience exhibited by the film is caused primarily by molecules within the film attracting those on the surface.

Students could have been given the explanation of surface tension first and then a series of laboratory exercises or demonstrations to verify the explanation. Many textbook-oriented courses present science this way. Taking a different view, we believe that students learn scientific principles in greater depth and with increased understanding if first they are given an opportunity to observe and then are asked to seek rational explanations for their observations. This is the essence of teaching science as inquiry. The text and laboratory materials should present only enough information for students to develop logical explanations based upon their ability to think and upon their previous knowledge. The teacher must encourage students to develop their own hypotheses and must supply the students with additional information as it is needed. This procedure is sometimes difficult; students tend to press the teacher for an answer before they make any effort to reason through a problem. However, the teacher must be careful not to discourage students by withholding answers to all questions for too long a time.

The study of surface tension provides information that supports a model based on the existence of very small particles, since surface tension is most realistically explained in terms of attraction between molecules of a substance.

Many excellent references are available to aid in understanding surface tension. A brief review of the subject follows. Our hope is that you will encourage students to develop a similar explanation on their own before you discuss surface tension with them.

Molecules of a given liquid tend to attract each other with equal force in all directions. In a dish of water, for example, water molecules attract each other with equal force in all directions, except where the water is in contact with the dish or with the air above. Water molecules have a greater attraction for glass than for each other. This accounts for the *meniscus*, or concave surface, of water in a glass tube. The smaller the diameter, the more pronounced the phenomenon.

The behavior of water molecules at the free surface in a dish of water is more difficult to explain, but understanding this behavior is essential to understanding the nature of bubbles and films. Water molecules are relatively close together and therefore have a strong attraction for one another. At the air-water interface, very little attractive force acts upon the water molecules from the air, because air molecules are very far apart. Because of this, the net molecular attraction at the air-water interface is not equal in all directions, and the water molecules attract each other both vertically downward and across the surface. As a result the water surface acts like a thin membrane (Figure T-2 • 1).

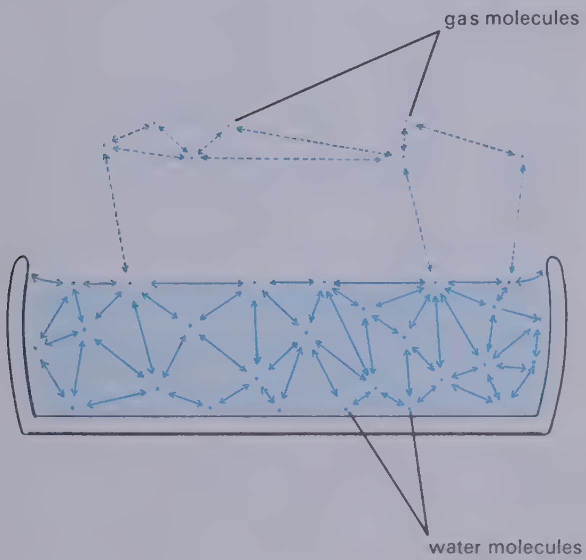


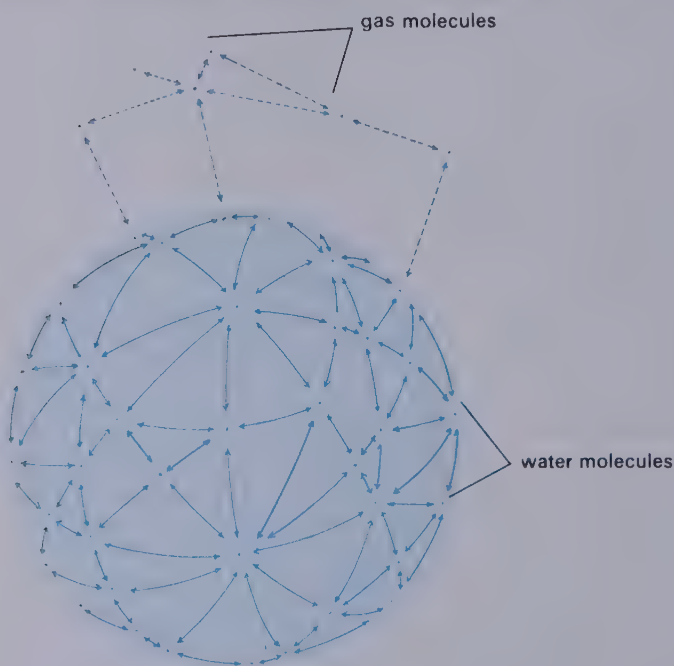
Figure T-2 • 1. Attraction among water molecules in a dish.

Because of surface tension, drops of liquid tend to be spherical in shape. This correlates with an elementary principle of geometry, i.e., the shape of an object with the smallest surface area relative to its

volume is a sphere. Liquids tend to assume a spherical shape when the forces acting upon them are equal on all sides (Figure T-2 • 2).

Molecules within a drop are attracted equally in all directions by other molecules. At the surface, however, the molecular attraction is unequal; molecules are attracted mostly toward the interior and across the surface, since there is very little attraction from outside the surface. Thus the surface of a drop acts as a continuous "skin," or "membrane," similar to the surface "membrane" in a dish of water.

Figure T-2 • 2. Attraction among water molecules in a drop.



INVESTIGATION 2.2: The Nature of Drops

(pages 38–41)

Students observe the behavior of water drops on different substances and are asked to propose models to explain the behavior.

MATERIALS

Several teachers report that the liquid hand soap found in most schools

gives excellent results and has the advantages of being easily available and inexpensive.

We have had good results with dilute liquid shampoo, but many other soap solutions will also give excellent results. It may be necessary to try different proportions of soap and water to achieve the best results, but the proportions used in mixing the soap (or detergent) solution are not critical. Because of differences in the hardness of water in various parts of the country, it is not possible to give exact specifications for the soap solution. Start with 80 ml of water and 20 ml of liquid detergent, and test the ability of the solution to form a film. Add liquid detergent—about 20 ml at a time—until good results are obtained. In class, use the proportions that give the best film. About 100 ml of solution per student should be sufficient. Detergents such as liquid Ivory or Breck shampoo yield good films.

PROCEDURES

A. Each student should begin the series of drops with the smallest he can obtain. A series of ten drops should give a good range of sizes.

B. Asking the student to predict the shape of the drops has two purposes: it should increase the precision of his observations, and it may provide a greater feeling of personal involvement in the investigation. Because of these goals, the procedure may achieve its purpose even if the prediction is completely in error. Students should be encouraged in the habit of making predictions before carrying out procedures.

C. The smallest drop will look almost spherical. The larger the drop, the flatter its upper surface will be.

D. The drops remain intact until they touch, at which time they instantly fuse into one.

E. Touching a drop of water with a clean toothpick should not change the overall shape or size of the drop. Surface tension is maintained, and the drop remains intact. A slight indentation of the water should be observed. During removal of the toothpick, the water surface may be distorted upward if the toothpick has become wet.

F. The water drop will tend to flatten out. Even a small quantity of detergent disrupts the molecule-to-molecule bonding of water and thus decreases surface tension.

G. Water drops will assume a spherical shape and sink to the bottom. The speed with which the drops sink increases with size. A very tiny (barely visible) drop will remain almost stationary. The last few drops squeezed from the dropper will rise to the surface. This should puzzle students and provide an additional opportunity for inquiry.

Water drops assume a spherical shape in oil since there is almost no attraction between water and oil molecules. Because of this the water drops are relatively free of outside attractive forces until they touch the glass at the bottom of the container. The last drops expelled from the dropper are mostly air and rise to the surface.

H. Drops of vegetable oil will rise to the surface and form clusters of drops. Careful observation reveals that the drops are spherical when immersed in the water but that they flatten out as they reach the surface. Since a discussion of density and specific gravity has not yet been introduced, it might be best to explain the action of water, oil, and air drops by noting that equal volumes of each substance would have different weights. Thus, oil moves up in water; air moves up in either water or oil. The following might be an interesting addition to this part of the investigation:

Gently place a drop of oil on the surface of the water in a clean beaker. The drop will appear to move about the surface in a slow, random fashion. If several drops are combined into one large drop near the center of the surface, smaller drops placed along the edge will move toward the center and adhere to the large drop. In contrast to the instant fusing of water droplets (Procedure D), oil droplets tend to remain separate. This poses an interesting question about the relative attractive forces of water molecules and oil molecules.

A possible explanation for the movement of smaller drops toward the larger is that the water surface is slightly depressed near the large drop, and thus the smaller drops may slide downward.

INTERPRETATIONS

1. The shape of a drop of water depends on three factors:
   a. Molecular attraction between water molecules
   b. Contact with a foreign substance and attraction to it
   c. Gravitational force
2. The larger the drop, the greater the surface area—and the greater the effect of gravity. The attractive force between water molecules does not change with increasing size, so the net effect is a flatter drop.
3. The molecular attraction between the water and each of the different surface materials varies. On plastic, the attraction is slight, so the droplets retain much of their spherical shape. On paper toweling, the attraction is great, so the droplets lose their characteristic shape completely and instantly.
4. The molecules in the two drops of water are mutually attracted when they touch, and the drops fuse immediately into one.

5. The overall shape of the droplet does not change except where it is touched by the toothpick. A slight indentation of the water should be seen by observant students. When the toothpick is removed, the drop will regain its original shape. Touching the droplet with a toothpick dipped in soap solution will reduce surface tension, and the drop will flatten out.
6. A prediction of either attraction or repulsion should be accepted. Based on their observation of the contact boundary between wax paper and water, students might predict that water will be repelled by wax. One activity that would test both predictions is to put a drop of water on a block of wax and turn the block over rapidly. If water is attracted to wax, it will stick to the block. If it is repelled by wax, it will be pushed off the block. (Small drops will adhere to a block of wax.) It would be worthwhile to provide a block of paraffin wax for students to use.
7. Explanations might resemble those in Figure T-2 • 3.

Behavior to Be Explained	*Possible Explanation Using the Demon Model*	*Possible Explanation Using a Structure of Matter Model*
The difference in shape between large and small drops of water on wax paper.	Demons don't like to be too close together, so the larger the group, the more they spread out.	Water molecules are most effective in attracting neighboring water molecules. Gravity flattens out a large drop because attraction is not great at larger distances.
The effect of soap on a water drop.	Soap demons are slippery, so they make it hard for the water demons to hold on to each other.	Soap molecules interfere with attractions between water molecules, so gravity can flatten the drop out more.
The behavior of two water drops when they touch.	Water demons like to mix with other water demons.	Water molecules attract each other.
The shape of a water drop when it is in oil.	Water demons are afraid of oil demons, so they crowd close together.	Water molecules attract each other.
The shape of a drop of oil when it is in water.	Oil demons crowd together for defense when they are outnumbered by water demons.	Water molecules attract each other and squeeze oil into the most compact shape. (A more likely student response: oil molecules attract each other.)

Figure T-2 • 3.

You might point out that so far no explanation has been offered for attractions between molecules (this will come in Section Three). The structural model, while sounding more sophisticated and scientific, may be more difficult for students to devise and at this point is really no more useful than the demon model.

INVESTIGATION 2.3: The Nature of a Film

In Investigation 2.2 you observed surfaces of drops, rather than entire drops. Often in science (and in mathematics), it is useful to consider what might be called an extreme case. Therefore, why not examine a "drop" that has the characteristic of being almost all surface—an extremely flat drop? A soap film has this desired characteristic and is the subject of this investigation.

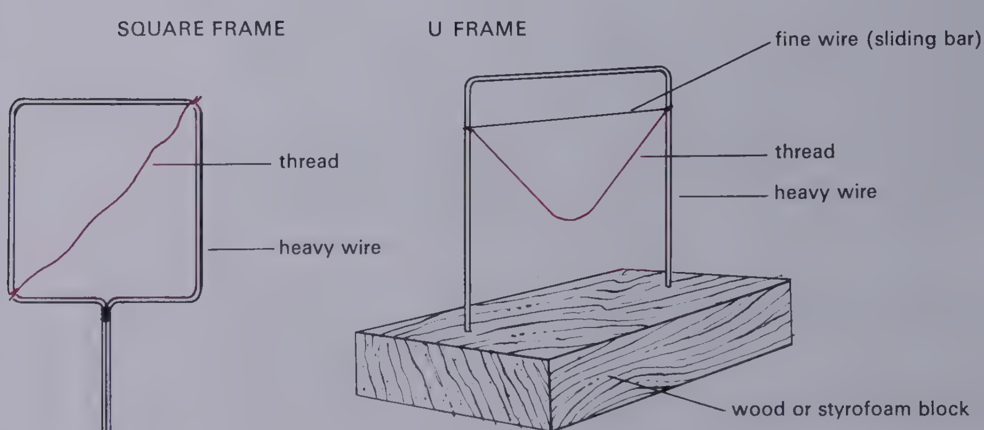
MATERIALS (per team)

- Thread
- Wire frames (Figure 2 • 16)
- Soap solution
- Large beaker or pan for soap solution
- Several toothpicks
- Small plastic or glass funnel
- Beakers (250 ml), 2

PROCEDURES

A. Tie a piece of thread to diagonally opposed corners of the square frame. Dip the entire frame into the soap solution. Carefully raise the frame out of the solution and observe the behavior of the thread. Make a sketch and record your observations. Puncture the film on one side of the thread with a

Figure 2 • 16. Wire frames to be used in Procedures A–C.



clean toothpick and observe what happens to the thread. Sketch what you see as accurately as possible. Repeat, puncturing alternate sides of the film.

B. Slide one end of the thread to a different corner of the frame and repeat Procedure A. Record your observations.

C. Dip the U frame (and sliding bar) into the soap solution, and remove. Gently grasp the sliding bar on both ends and pull it slowly toward the block. Predict what will happen when you release the bar. Release the sliding bar and observe the effect. Was your prediction correct? Record your observations.

D. Form a film on the large end of the glass funnel by gently dipping it into the soap solution. Cover the small end of the

Figure 2 • 17. Carrying out Procedure D.

funnel with your finger and raise the funnel from the solution. Before continuing, predict what will happen to the film when you remove your finger from the funnel. Hold the funnel at eye level as shown in Figure 2 • 17 and remove your finger. Observe and record in your notebook any change in the film.

E. Repeat the steps of Procedure D and then dip the funnel into the soap solution to form a second film. Record your observations carefully.

INTERPRETATIONS

1. As in Investigation 2.2, the following questions should serve only as guidelines, not as restrictions on your thinking:
   a. In Procedures A and B, you punctured one half of the film. What does the behavior of the thread following a puncture suggest about the properties of atoms or the behavior of demons?
   b. How could demons or the structure of atoms account for the reactions of the soap film and the sliding bar after it is released?
   c. What properties of atoms or demons could cause a film formed on the large end of a funnel to behave as it does?
2. Combine your observations from Investigations 2.2 and 2.3 to write a description of a model that explains how the behavior of water is related to the particles which join together to make water drops. Make two columns for your answer. In the first column, write the *properties* of demons or atoms. In the second column, write the *observations* each property of demons or atoms explains.

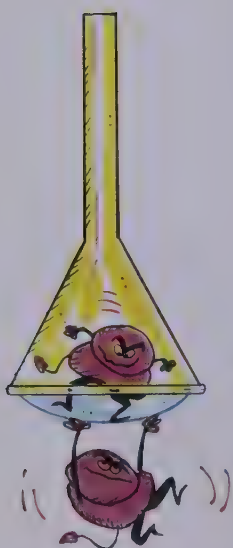


Figure 2 • 18. A possible explanation for the behavior of films in Procedures D and E.

INVESTIGATION 2.3: The Nature of a Film

(pages 42–44)

Soap films reduce their sizes to produce the smallest available area. Students can observe this phenomenon and use the information they gain to build their models for the structure and behavior of matter.

MATERIALS

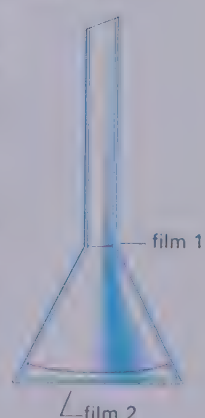
Construction of the wire frames may be assigned to one or two students, or each student might be asked to prepare his own apparatus.

The dimensions of the frames illustrated in Figure 2 • 16 are probably not critical. We have used soft wire to make square frames about 2 x 2½ inches and U frames about 2¼ x 5 inches. The sliding bar on the U frame must be as light as possible, or the film will not lift it. A single strand of wire from an extension cord made of many small wires works very well. The container for the soap solution must be large enough to permit dipping of both frames.

PROCEDURES

A. If the solution is well prepared, the procedure causes no problem.
B. The thread can be carefully moved to different locations without breaking the film.
C. If this is done carefully, the film does not break. When released, the bar is pulled back to its starting position by the attraction of the water molecules for one another.
D. When the finger is removed from the small end of the funnel, the soap film moves toward the neck of the funnel. Molecular attraction within the film causes it to move to a point where it has the smallest attainable surface area.
E. With a film intact at the neck of the funnel, the large end of the funnel is again immersed in the soap solution. The new film does not move upward; there are now two films, and the pressure of the air between them keeps them apart (Figure T-2 • 4).

Figure T-2 • 4.



INTERPRETATIONS

1. Parts *a*, *b*, and *c* all refer to the elastic behavior of a soap film and can be explained by the same answer.

   A possible answer using properties of atoms: atoms attract each other; atoms that are free to move are pulled closer by the attraction. A possible answer using properties of demons: demons like to be close together, and they pull on particles of matter until they achieve a situation they are happy with.

2. In giving reasons for their statements, students are carrying out a fundamental activity of science: the relating of experimental results and the interpretation of those results in such a way as either to build more confidence in the model or to provide evidence that makes the model unsatisfactory.

Class discussion may help students who have difficulty with this interpretation. They should be helped to realize that both models assume the existence of particles. The models differ in explaining why the particles behave as they do. You may find it useful to list student responses on the board. The format shown in Figure T-2 • 5 will emphasize parallels between the models. Any

Figure T-2 • 5.

Properties of the Model		*Observations*
Structure of Matter Model	*Demon Model*	
Different substances are made of different kinds of molecules.	Different kinds of particles are controlled by different kinds of demons.	Oil, water, soap, plastic, wax paper, and paper toweling behave differently.
Molecules of a single substance attract each other. Attractions cause groups of molecules to contract into the smallest space they can.	Demons of one kind like each other. Demons that like each other pull their particles of matter close together.	Water drops join when they touch.
Molecules of some different substances attract each other.	Demons of some different kinds like each other and enjoy being close together.	When a film containing a thread is punctured, the side where the film remains pulls on the thread. After a film is stretched with a sliding bar and released, the film shrinks by pulling the sliding bar close to the fixed one. In a funnel, a film becomes smaller by moving toward the neck.
Molecules of other different substances repel each other.	Demons of other different substances don't like each other and try to separate their materials.	Water drops of the same size have different shapes on different kinds of surfaces. Water drops separate from oil, and oil drops float on top of water.
Attractions between different kinds of molecules in mixtures may be less than attractions when in separate substances.	Even when different kinds of demons are willing to mix, they may partially interfere with each other's pull on particles.	Soap causes a water drop to spread out.

reasonable statement should be accepted. Conflicting properties may exist between models proposed by different students; but each student's model should be internally consistent. A sample response is listed in Figure T-2 • 5.

ON YOUR OWN: Two Problems

I. In this investigation you will be given very little direction. As you carry out the procedures, try to remember what you have learned in Investigations 2.1–2.3 and apply your knowledge in answering the questions.

MATERIALS

Square wire frame
Soap solution
Small jar

PROCEDURES

A. Form a soap film that will cover the entire wire square.
B. Place a jar directly under a faucet.
C. Hold the film and wire under a *small* but steady stream of water so that the stream passes through the film and into the jar.
D. Describe, in detail, what happened. Repeat the investigation as often as you wish.

QUESTIONS

What were the results of your investigation? How would you explain these results?

II. As in other investigations of this kind, you are given very little information. You will have a chance to use what you have learned in attempting to solve a kind of scientific puzzle. Your work should be carried out at home or after class at school.

MATERIALS

Drinking glass (must be glass—not a paper cup)
Straight pins, 1 box
Paper towels
Water
Beaker, pitcher, or other container

PROCEDURES

A. Add water to the glass until it is almost full.

B. *Carefully* place the glass of water on a flat surface that has been covered with several paper towels.

C. Now very gently add water until the glass is completely filled. *Do not* spill any water on the paper towels.

INTERPRETATIONS

1. Predict how many pins you can add to the glass of water before some of the water begins to spill out of the glass and onto the towels.

PROCEDURES

D. Now, start adding the pins, one or two at a time, until water spills over the rim of the glass. Be very careful not to touch the water as you add pins.

INTERPRETATIONS

2. Was your prediction correct? How many pins were you able to add? Describe and try to explain your results.

   Suggestion: use a graduated cylinder to verify your results.

Figure 2 • 19. This insect can walk on water. What keeps the insect from sinking?

ON YOUR OWN: Two Problems

(pages 45–46)

I. This is the first of many unstructured investigations that students will be asked to carry out on their own.

We suggest that you offer no help in any way. Let the student discover for himself an interesting phenomenon and offer a sound explanation for his observations.

The water should pass through the soap film for several seconds without breaking the film. As the film becomes more and more diluted, it will break.

By examining the water-soap mixture in the collecting jar, students should come up with this explanation on their own.

II. In the test run for this investigation, a glass 17 cm high and 7 cm wide was used. Five hundred pins were added to the full glass of water without any water spilling over the edge. The pins occupied almost half of the glass of water. We ceased adding pins at this point.

INTERPRETATIONS

1. Students will probably underestimate greatly.
2. There are three plausible answers to this phenomenon:
   A. People rarely *completely* fill a glass with water. The glass only appears full.
   B. There is a lot of space between the pins.
   C. Most important, the pins *do* displace water, but because of surface tension, the displaced water forms a bubble at the top, thus raising the water level above the rim of the glass. Adding the same number of pins to a 100-ml graduated cylinder ⅔ filled with water showed that the water level rose about 10 ml.

Avoid giving students hints or aiding them in any substantial way. Let individual students try this on their own. They should get a "feel" for conducting their own research on an individualized basis.

Components of Matter

The chalk particles used in Investigation 2.1 all resemble one another, except for size and shape. They all have the same color and texture. If you could continue breaking the chalk particles apart, do you think there would be one kind of particle, or might there be several kinds? What holds the particles together? If you were able to break the particles into atoms, would all the atoms behave the same way?

The composition of chalk cannot be changed by simple means, such as crushing. Chemical experiments show that chalk contains at least two different substances—oxygen gas and a soft, silver colored metal. Although you can separate chalk into these substances, try as you may, you cannot separate these two substances into any other materials.

INVESTIGATION 2.4: A Dye Spot

Breaking down chalk would be very difficult. So that you may gain some experience in separating matter, materials that are easier to work with have been selected for this investigation. When you look at a sample of matter, it may not be possible to tell if it can be broken apart, but if substances are chemically different, it may be possible to use their differences in behavior to separate them.

MATERIALS (per team)

- Strip of filter paper with dye spot
- Paper clip
- Mason jars or drinking glasses, 2

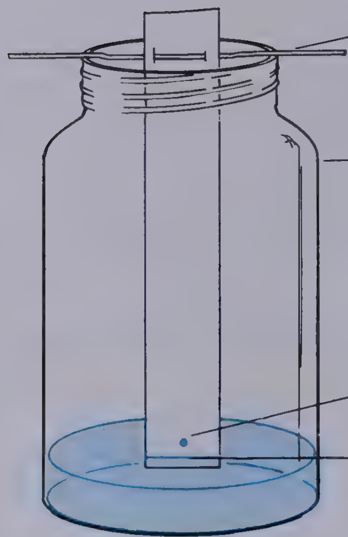


Figure 2 • 20.
Setup for
Procedures A–D.

PROCEDURES

A. Pour about 20 ml of water into one of the jars. A spot of green dye has been placed near one end of the filter paper. Hold the filter paper against the *outside* of the jar so the dye spot is a short distance above the water level. Push a straightened paper clip through the filter paper at the level even with the top of the jar.
B. Lower the filter paper into the water until the clip rests on the jar (Figure 2 • 20).
C. Leave the filter paper in the water until the paper is saturated to the level of the paper clip.
D. Remove the filter paper from the water and hang it in an empty jar to dry. Do not touch the paper.

INTERPRETATIONS

1. What information does this investigation provide about the dye spot?
2. What properties of matter do you believe are responsible for the behavior you observed?

3. Suggest additional models to explain what you have observed. You might describe the behavior of demons or of some other factor to explain why the dye behaved as it did. Make your own illustrations, if necessary.

ON YOUR OWN: Investigating Mixtures

As a home or after school activity, try to separate other liquids into different parts, using the same general methods used in this investigation. In place of water, you may wish to try vinegar, rubbing alcohol, or a mixture of one or both with water. In addition to filter paper, try other kinds of paper.

CAUTION: *Do* not *use highly inflammable liquids such as gasoline or cleaning solvents. Also avoid using liquids that may give off poisonous fumes. If in doubt, ask your teacher.*

Matter to be separated might include different inks, tomato juice, or some other kinds of household materials.

Within the bounds of common sense and caution, let your imagination and curiosity be your guide. You may wish to record your results in a report entitled, *Separating Matter with Liquids.*

INVESTIGATION 2.4: A Dye Spot

(pages 47–49)

Do not attempt an in-depth study of paper chromatography in this investigation. We have deliberately avoided using the term *chromatography* to give teachers wide latitude in the method of presenting this investigation. The exercise is intended to be an observation of certain behavior in matter. It will also help build a foundation for developing the atomic-molecular theory of matter.

MATERIALS

The depth of water in the drinking glass or mason jar should be about ½ inch. The length of the filter paper should be about equal to the height of the container. The paper will be supported at the top and still reach a little below the level of the water. The paper should be at least 5 inches long and about ½ inch wide. Whatman *student grade* filter paper allows the water to rise at a suitable rate (about 1 inch in five minutes). If the paper you selected allows the water to rise too rapidly, it may not provide a good separation. If the water rises only half as fast as recommended, the separation may be much better, but this requires more time than is likely to be available.

Green food coloring is a good substance for illustrating the separation of matter. The dye tested for this investigation is a mixture of yellow and blue pigments. Test the food coloring before conducting the investigation to be sure that the pigments can be separated.

We suggest that you prepare the strips of filter paper for the students, to insure that this is done properly. Using an old pen, place a dot of food coloring about ¾ of an inch from one end of the filter paper. It should not be applied so heavily that it spreads more than 2 or 3 millimeters.

PROCEDURES

Students will have little difficulty carrying out the procedures if you select, prepare, and test the materials beforehand, as suggested above.

INTERPRETATIONS

1. The investigation shows that the dye can be separated into different colors. Green food coloring often separates into three distinct color bands. The order of color (from the bottom) is yellow, green, and blue. Students are likely to conclude that the color bands represent three different substances.

NOTE: *Actually there are only two substances in the dye. The yellow and blue bands represent these substances. If the chromatogram is set up to develop horizontally instead of vertically, only yellow and blue bands are seen. The same result can be obtained if the separation is done vertically on much longer paper in a taller container. The green color is caused by the mixing of blue and yellow pigments. Describe what happens when a longer paper is used and ask students to explain what must have happened to the green color.*

2. It is not always easy to explain the separation of substances by paper chromatography. In this investigation only one solvent—water—is used. Separation depends on two factors: the difference in solubility of the substances in the solvent and the difference in the degree with which they are adsorbed by the paper. The greater the degree of adsorption, the slower a substance will "move" on the paper. Also, the greater its solubility in the solvent used, the faster the substance will move. Students are not likely to be able to explain the separation in such detail. You may wish to postpone a discussion of why the separation occurs. In the meantime the students may find it easy to explain the separation in terms of the behavior of demons.
3. A model to support a demon theory might include the following:
   a. Demons like to separate colors.
   b. If the material is dry, the work is too difficult for them; but in a liquid, demons are free to move about and separate the different substances more easily.
   c. Blue particles are easier to move, so the demons can push them farther along the paper.

A discussion of the demon theory might stimulate students to design a model based upon the kind of answer given for Interpretation 2.

ON YOUR OWN: Investigating Mixtures

(page 49)

There is no way to predict how many substances students will select or what their results might be.

In addition to providing an opportunity for individualized study, this investigation and others of the same type may involve cooperation between student and parents. This would be a desirable outcome.

INVESTIGATION 2.5: Another Look at Size

The preceding investigations have given you a chance to find out something about the size and behavior of certain kinds of atoms.

You should be able to improve your estimate of the size of particles of matter in this investigation. Calculations using the data developed in this investigation let you say that atoms can be no *larger* than the calculated value.

MATERIALS (per team)

Pint jars or beakers, 2
100 ml of a starch suspension
100 ml of dilute, brown IKI solution
Dialysis tubing, 2 6-inch pieces
Paper clips or rubber bands
Hand lens
Medicine droppers, 2
Small glass plate
Aluminum pan
Chalkboard erasers
Toothpicks
Liquid soap

CAUTION: *Be careful not to spill or splash the brown solution. It will stain clothing and skin.*

PROCEDURES

A. Label the jars *1* and 2.
B. In Jar 1 prepare a starch suspension by adding starch to water until the mixture becomes cloudy in appearance.
C. Add 100 ml of dilute, brown IKI solution to Jar 2.
D. Use a hand lens to examine the walls of the dialysis tubing.

INTERPRETATIONS

1. Can you see any holes in the wall of the tube?

PROCEDURES

E. Place one drop of each solution on the glass plate. The drops should be close to each other but not touching. Before using the droppers, rinse them in water. Do not use the same dropper in both solutions. Examine each drop with the hand lens.

INTERPRETATIONS

2. Can you see any particles in either drop?
3. What evidence does an examination of the two liquids give that particles in one liquid may be larger than particles in the other?

PROCEDURES

F. Use a toothpick to move one drop so it mixes with the other. Observe and record the result.

INTERPRETATIONS

4. How can you tell when a starch suspension and the IKI are mixed together?

PROCEDURES

G. Tie a knot in one end of each piece of tubing. Fill one tube with starch suspension from Jar 1; fill the other tube with IKI solution from Jar 2. Twist the open end of each tube. Fold it over and fasten it with a paper clip or rubber band.

H. Place the tube with IKI solution in Jar 1 (starch) and the tube with starch in Jar 2 (IKI), as shown in Figure 2 • 21.

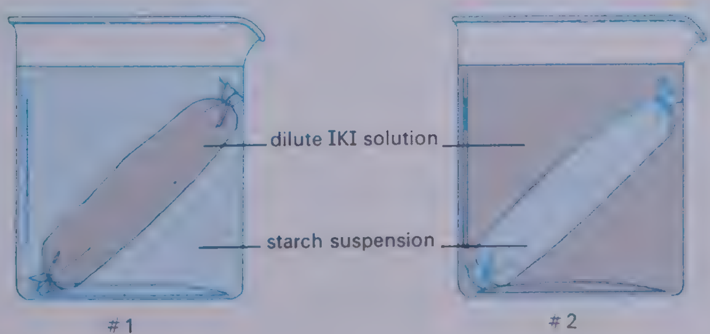


Figure 2 • 21. Setup for Procedures G and H.

I. Both jars should be left undisturbed for fifteen minutes. Observe and record what occurs in each jar.

INTERPRETATIONS

5. Describe and explain any changes that occurred in the jars.
6. Which substances appear to move through the membrane? Relate your answer to the size of particles involved.

PROCEDURES

J. Pour water into the aluminum pan until it is about half full. Hold the erasers above the water and gently tap them so that the surface of the water near the center of the dish is covered with a *light* coating of chalk dust.

Predict what will happen if you add a droplet of soap to the dish of chalk-covered water. Record your prediction.

Dip the end of a clean toothpick into the liquid soap. Obtain a small droplet of soap on the point of the toothpick and measure the *diameter* (distance across) of the droplet. Record the measurement in your notebook.

Carefully lower the droplet over the center of the dish until it just touches the chalky surface. Record your observations.

Measure the diameter of the droplet of soap after it has been added to the water.

INTERPRETATIONS

7. Was your prediction about what would happen to the droplet of soap correct?
8. Compare your results with those of other groups.
9. Compare the diameter and volume of the droplet of soap before it was placed in the water with its diameter and volume after it was added to the water.

An End and a Beginning

The presence of demons could be used to explain what you have observed about the behavior of matter. Investigations in Section

Two also provided evidence that matter may be composed of many small particles. This information can be used to develop a model to explain the behavior of matter. The idea that matter is made up of small particles, called *atoms* and *molecules*, and that the behavior of any substance depends on the properties of these particles is called the atomic-molecular model of matter.

The investigations in Section Two do not *prove* that the atomic-molecular model is true, but they do provide substantial evidence for the existence of atoms and molecules. Scientists are continually seeking new evidence to support this model of matter.

The world of atoms can be as challenging to explore as outer space. Scientists continue their search for knowledge about atoms as well as about planets. If the present rate of scientific advance continues, knowledge about our environment will probably double within the next ten years. What changes this knowledge will bring cannot be known, but we can be sure that life will be different.

By investigating, observing, interpreting, and communicating, scientists throughout the world have developed a model that helps to explain, as well as predict, the behavior of matter. This model has been developed partly from experiments that required complicated equipment and advanced knowledge. But it also has been constructed from investigations quite similar to those you will perform in the following sections of this course.

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INVESTIGATION 2.5: Another Look at Size

(pages 50–52)

This investigation provides evidence for the particulate nature of matter. Students also should learn techniques useful in later investigations. This investigation is an extension of Investigation 2.1 and places a more refined upper limit on the size of the smallest particles of matter.

MATERIALS

The ruler should be calibrated in both metric and English units. Round aluminum pie pans can be supplied by students or purchased at local stores at little cost. Almost any liquid soap or detergent serves the purpose of the investigation. Shampoo or the soap used in school washrooms is adequate. Teachers report that drops of some of these products often sink to the bottom of the dish. If this should occur, dilute the soap with water.

Dialysis tubing can be purchased from several biological supply companies.

A dilute solution of IKI can be made with 1 g of iodine crystals and ½ g KI in 100 ml of distilled water. This solution is called *brown solution* to avoid the use of chemical symbols at this time.

PROCEDURES

A.–B. No comment.

C. Remind students that the brown solution stains.

D. The holes which permit diffusion are too small to be seen with a hand lens.

INTERPRETATIONS

1. Students should not be able to see holes in the tubing walls.

PROCEDURES

E. You may prefer to have one or two dropper bottles of each solution available in the room, rather than let students use droppers in their own solutions.

INTERPRETATIONS

2. Neither drop should contain visible individual particles.
3. The starch suspension is cloudy while the brown solution is clear. Students might suggest that cloudiness could indicate larger particles. A correct answer at this time is not required, and any reasonable statement should be accepted.

PROCEDURES

F. When the drops mix, they turn dark (purple to black).

INTERPRETATIONS

4. The starch suspension and the brown liquid turn dark when they mix.

PROCEDURES

G. It is critical that the lower end of each piece of tubing be securely knotted; any movement of materials in or out of the "cell" must be through the membrane, and not through a leak in the end of the tube. Closure of the upper end may also be accomplished by knotting or by tying a string around it.

H. Students should be sure that anything spilled on the outside of the tubing is rinsed off with water before starting this procedure. Small dishes can be substituted for the jars. Pour starch suspension or IKI solution into the dishes until the membranes are about half immersed.

I. No comment.

INTERPRETATIONS

5. The starch suspension in Jar 1 should have changed from white to purple. The starch suspension inside the membrane in Jar 2 should have changed to purple.
6. Apparently, the brown solution can move through the wall of the tube while starch cannot. Students should suggest that particles of starch may be larger than particles of the brown substance.

PROCEDURES

J. If you have an overhead projector, you may find it very effective to demonstrate this procedure before asking the students to do it. For best results the layer of dust should be very thin.

When the droplet is placed in the center of the dish, the results are usually dramatic. Almost immediately the droplet spreads into a film that covers all or most of the water surface, and the chalk dust is swept to the sides of the pan. The soap film is not visible, but the layer of dust serves to outline its edge.

As an additional activity, you may want to substitute other substances for the chalk. Sulfur dust makes an interesting alternative since soap will cause it to sink.

INTERPRETATIONS

7. It is not possible to anticipate students' predictions. They may sug-

gest that the droplet will float, sink, shrink, or expand. It is unlikely they will predict the droplet will cover all or most of the water surface.

8. While some groups may get a star-shaped pattern, others should get a circle. It is easier to compare the diameter of a circle with the diameter of the drop before it is put on the water. Encourage students who get a star pattern to repeat, using a thinner coat of chalk dust and a smaller soap drop.
9. The diameter of the film will be much greater than the diameter of the droplet. The volume should be approximately the same. Before going on, be sure all students realize that the content of the sphere is now spread out over the surface of the water. Therefore the film *must* be very thin, and the particles in it must be very small. If the students have trouble realizing that the volume has not changed, it might be helpful to show them several containers with different shapes but the same volume. Pour the same amount of water into each of them.

CALCULATION

This calculation could be demonstrated to students of average ability or assigned as a problem to above average students.

Calculation of the thickness of the film formed by the droplet can be done as follows: compute the volume of the droplet from the formula $4/3\pi r^3$ (volume of a sphere), where r is the radius of the droplet and π is 3.14. This volume is only approximate since the students cannot measure the diameter of the droplet with much precision.

Even though the droplet is now spread out as a film, its volume has not changed. Since the film approximates the shape of a very wide, thin cylinder (Figure T-2 • 6), its volume can be calculated from the

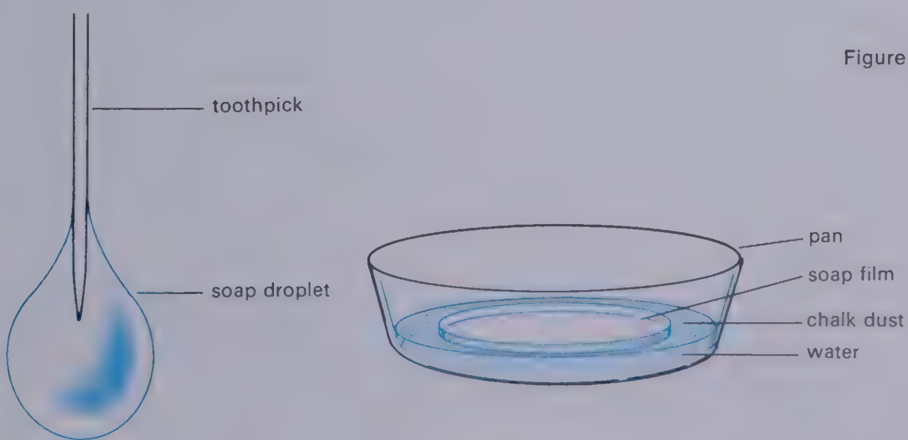

Figure T-2 • 6.

formula $\pi r^2 t$, where r is the radius of the film and t is its thickness. Since the volume of the drop and the volume of the film are about equal, we can calculate the approximate thickness of the film by solving for t. If your students have trouble with these calculations, work them out together on the chalkboard. It is more important that the students see the logic used to obtain evidence for the upper limit of the size of the soap particles than that they work out all the mathematics by themselves.

If you wish to simplify this calculation, $4r^3$ is approximately equal to $4/3\pi r^3$.

NOTE: *A concrete example may help students to understand how this calculation applies to their model of the structure of matter. A volume of lead shot can be measured in a graduated cylinder, and the shot can be poured out to form a thin layer. The thickness of the layer can be calculated by equating the measured volume to the volume of the layer. After the thickness has been computed, it could be measured for a direct check. If you don't have lead shot, a granular substance such as sugar or fine sand could be substituted.*

SAMPLE CALCULATION

Radius of droplet $= 0.04/2 = 0.02$ cm
Volume of droplet $= 4/3\pi\ (0.02)^3 = 0.00003\ \text{cm}^3$
Radius of film $= 25/2 = 12.5$ cm
Volume of film $= \pi r^2 t = 492t$
Since the volumes are equal:
$492t = 0.00003$
$t = 0.00003/492 = 0.00000006$ cm, or 6×10^{-8} cm

This is a worthwhile calculation, since a relatively simple experiment permits you to obtain a value within or close to the range of atomic dimensions.

FOR FURTHER DISCUSSION

Ask the students what errors might be involved in calculating the volume of the droplet and film (Figure T-2 • 7 and T-2 • 8) and what the consequences of these errors might be. A valuable class discussion on experimental error and bias may result.

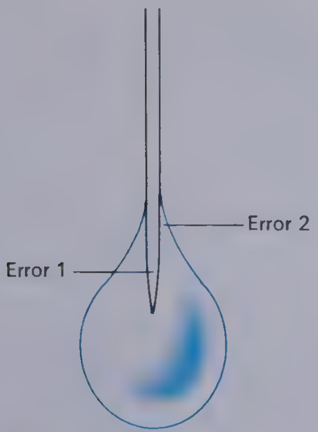

Figure T-2 • 7.
Errors possible in calculating volume of droplet: the toothpick occupies space in the drop; some solution remains on toothpick after transfer of the drop. Thus the volume deposited is less than calculated.

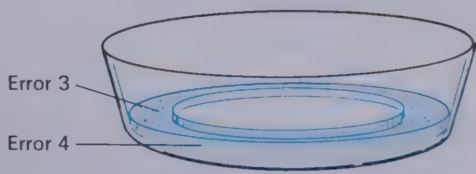

Figure T-2 • 8.
Errors possible in calculating volume and dimensions of the film: the chalk may prevent further spreading of the film; some soap may dissolve or sink. Thus the film could be thinner than the calculations will indicate. Corrections for each error would reduce the calculated particle size.

SUPPLEMENTARY MATERIALS

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FILM

Evidence for Molecules and Atoms. Encyclopaedia Britannica Film #1886. 19 minutes. Color. The film shows Brownian motion, crystal formation, and the behavior of solutions as evidence for differences in the structure of matter. Do not use the film prior to completion of the laboratory activities in this section.

FILM LOOP

The Motion of Small Particles. Interaction Film Loops, Inquiry in Physical Science. Chicago: Rand McNally & Co., 1972.

SUGGESTED ACTIVITIES FOR TESTING LABORATORY SKILLS AND TECHNIQUES

Because IME is a laboratory-oriented course, one of its goals is to ensure student mastery of certain basic laboratory skills and techniques. Often a student's difficulty in arriving at reasonable interpretations may result from errors made in measuring, weighing, or manipulating simple equipment. Unless students know (or at least suspect) that a check of these skills and techniques will be made, some of them may sit back and let others do most of the work during investigations.

Listed below and at the end of subsequent sections whenever appropriate are specific activities suggested as items for "practical" examinations to test laboratory skills and techniques. The list is in no sense exhaustive; the imaginative teacher will have no difficulty developing many additional activities from the text or from related laboratory experiences. Although a number of the activities proposed here may seem quite elementary, experience has shown that mastery of even such simple skills cannot be taken for granted.

The suggested activities are keyed to investigations in the student text. You can observe the student at his own station or at a demonstration table, and evaluate his performance.

INVESTIGATION 2.1

Measure, in centimeters, the length and width of a rectangular object.

INVESTIGATION 2.1

Count some objects visible only through a land lens.

INVESTIGATION 2.2

Using a dropper place a small drop of water on a glass plate.

INVESTIGATION 2.2

Sketch a drop of water that is on a glass surface.

INVESTIGATION 2.4

Pour a specified volume of water into a graduated cylinder.

SECTION THREE

Classification of the Elements: The Structure of Atoms

SECTION THREE

Classification of the Elements: The Structure of Atoms

(pages 55–79)

Preview

Early scientists recognized the need to classify matter so that the many different properties of substances could be studied and compared more easily. From photographs and from data on the appearance of some elements, students are asked to develop their own classification scheme. We believe that students will better understand classification if they are allowed to build their own systems. We urge that students be given great latitude in their attempts to classify elements in the manner they see fit.

Since our modern system of classification is largely based on the "ability" of atoms to gain or lose electrons, a teacher demonstration on static electricity and a student investigation on static charge follow. Both involve the addition or removal of electrons. We urge that you carry out the demonstration—it is an integral part of the section.

The idea of like charges repelling each other and unlike charges attracting each other is given considerable attention in this section since this concept is fundamental to student understanding of inorganic chemistry.

Other activities with static electricity are given on page 62C for students who may wish to pursue this subject in greater detail, providing additional opportunity for individual study.

The experiment of Ernest Rutherford (1871–1937) further illustrates the historical development of a modern model of atomic structure.

While many subatomic particles have been discovered over the years, major emphasis is given to electrons, protons, and neutrons, for it is upon these subatomic particles that the modern classification of elements is based.

A model of the internal structure of an atom is gradually developed, beginning with the Bohr model and ending with an electron cloud model to show possible arrangements of electrons, protons, and neutrons.

A very important Inquiry Demonstration illustrates the concept of electron transfer during a chemical reaction. A student investigation follows which illustrates a similar reaction. The term *ion* is omitted in favor of *charged particles*. Ions will be introduced in Section Five.

Section Three leads directly to the expanded modern classification of elements in Section Four.

Although we hold technical terminology to a minimum, we find it necessary that students learn the meaning of certain terms used frequently in the course. Discuss the terms *element, compound, atom,* and *molecule* as they are introduced, to assure that students clearly understand their meaning.

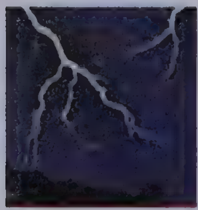
PLANNING AHEAD

Consult Appendix D, "Equipment and Supplies for a Class of 32 Students" (page 350), for a list of equipment and chemicals needed for Section Three. Reading and audiovisual references are listed at the end of the section.

LEARNING OBJECTIVES

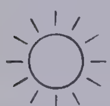
Given the opportunity to inquire, to investigate, to interpret data, and to offer hypotheses about the activities in this section, most students should be able to—

- Explain the scientific importance of classifying or grouping data;
- Establish criteria and patterns for classifying information;
- Sort and classify data into simple groups or lists based upon established criteria;
- Recognize symbols and describe several elements;
- Demonstrate the electrical nature of some kinds of matter;
- Devise a system to demonstrate and determine the type of charge placed on a ruler;
- Explain the relation of Ernest Rutherford's experiments to a model for matter;
- Describe the similarities and differences among the major subatomic particles;
- Describe the historical evolution of the atomic model;
- Explain charged particles as the result of electron gain or loss;
- Manipulate and use simple laboratory apparatus (interacting charged rulers, clamps, battery, wires, dialysis tubing, milliammeter, Bunsen burner).



You have made some of the same observations and performed some of the same kinds of investigations that led scientists to construct a model for the behavior and structure of matter. You have observed that the smallest particles of matter must be too small to see. And like Democritus, you have used the term *atoms* as a name for these particles.

Figure 3 • 1. Symbols for gold that have been used in the past. Why do you think modern scientists use Au as a symbol for gold?



fifteenth century

sixteenth century

1783 (Bergman)

1808 (Dalton)

1814 (Berzelius)

As you have seen, matter can be separated into different kinds of substances. Therefore, there must be different kinds of atoms. If these different kinds of atoms are classified into groups, their properties may be studied more easily. Biologists do the same thing when they classify kinds of trees—oaks, pines, willows, and so forth. Geologists classify minerals, and astronomers place stars, planets, moons, and meteors in separate groups. Classification—the grouping of things in an orderly manner—is an important and useful part of science.

According to our present atomic model, all the substances familiar to us are made up of atoms of elements. An *element* is a substance that cannot be broken down by chemical means into any simpler substances. Gold is an element because the smallest particle of gold dust still has the properties of gold.

An *atom* is the smallest possible unit of an element. An atom of gold is the smallest possible particle of gold.

Gradually scientists began to use a set of symbols—one for each element. Symbols are used for convenience, and very often they contain clues to what they represent. The modern symbol for gold—*Au*—is taken from the Latin word *aurum*, meaning "gold." Symbols for some of the elements have been used since the fifteenth century (see Figure 3 • 1).

The system of element symbols now used throughout the world was introduced in 1814 by Jöns J. Berzelius, a Swedish chemist. Most symbols are initials or abbreviations of the Greek or Latin names for the elements. Since the names of several elements start with the same first letter, a second letter has been added to some of the symbols to avoid confusion. For example, the symbol for carbon is C; for calcium, Ca; for cesium, Cs. Symbols and pictures of some common elements are shown in Figures 3 • 2 and 3 • 3.

Element	*Symbol*	*Description*
Aluminum	Al	Silvery metal
Argon	Ar	Colorless gas
Beryllium	Be	Silvery metal
Boron	B	Yellowish-brown crystal
Carbon	C	Black crystal
Chlorine	Cl	Greenish gas
Fluorine	F	Pale yellow gas
Helium	He	Colorless gas
Hydrogen	H	Colorless gas
Lithium	Li	Silvery metal
Magnesium	Mg	Silvery metal
Neon	Ne	Colorless gas
Nitrogen	N	Colorless gas
Oxygen	O	Colorless gas
Phosphorus	P	Red, white, or yellow crystal
Silicon	Si	Silvery gray crystal
Sodium	Na	Silvery metal
Sulfur	S	Yellow crystal

Figure 3 • 2. Symbols and descriptions for eighteen common elements.

Grouping Elements by Appearance

You are already familiar with a number of elements, such as gold, silver, iron, copper, and oxygen. Your first problem in Section Three is to find a way to arrange the eighteen elements in logical groups based only on the information given in Figure 3 • 2.

Use any system you wish for grouping. After completing the problem, compare your system of grouping the elements with those used by other students.

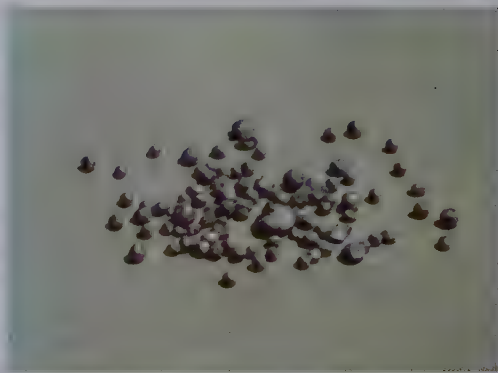
INTERPRETATIONS

1. Describe the advantages of your method of grouping elements.
2. Describe what you believe to be the disadvantages of your method of grouping.
3. What are some advantages of using symbols for the elements?

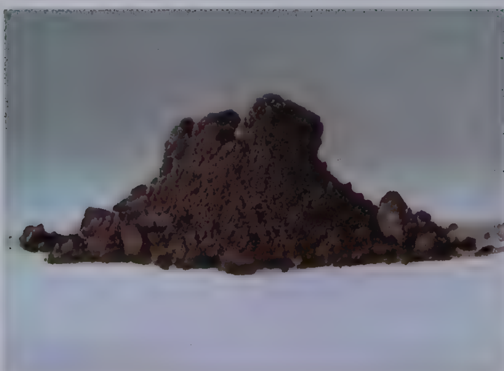
Figure 3 • 3. Photographs of some of the elements shown in the table on page 57.

Aluminum.

Beryllium.

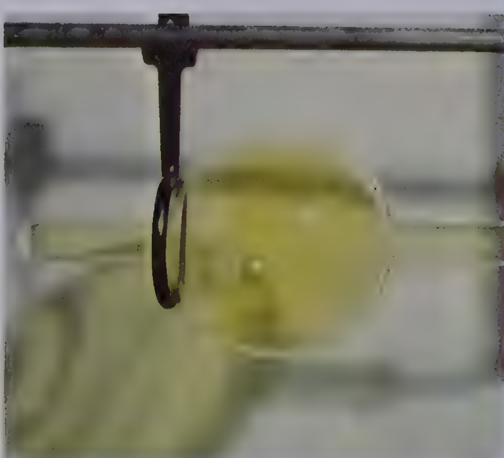


Boron.



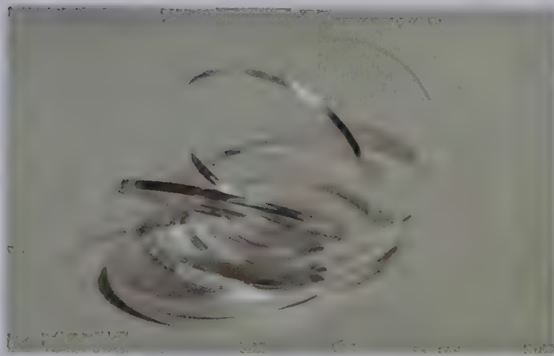
Carbon.

Chlorine.



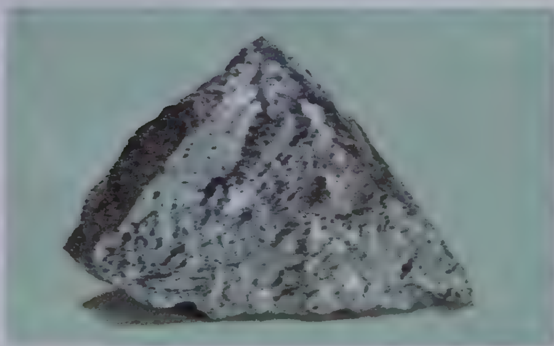
Fluorine.

Lithium, photographed in kerosine.

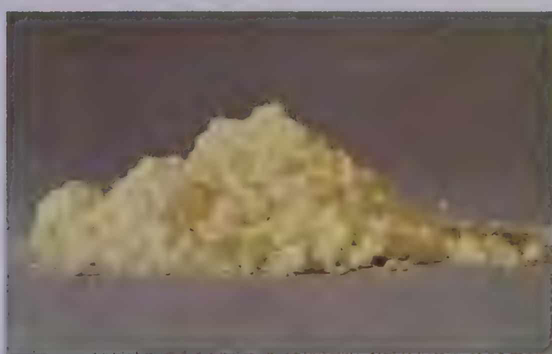


Magnesium.

Phosphorus (yellow), photographed in water.



Silicon.



Sulfur.

Sodium, photographed in kerosine.

Grouping Elements by Appearance

(pages 57–59)

Students may group the elements by appearance (Figure T-3 • 1). Other arrangements, such as groupings by color, may be suggested by students. Point out that arranging elements alphabetically (also shown in Figure T-3 • 1) is a form of classifying, too.

Figure T-3 • 1.

Metals	*Gases*	*Crystals*
Aluminum	Argon	Boron
Beryllium	Chlorine	Carbon
Lithium	Fluorine	Silicon
Magnesium	Helium	Phosphorus
Sodium	Hydrogen	Sulfur
	Neon	
	Nitrogen	
	Oxygen	

INTERPRETATIONS

1. Responses will vary. Give fair consideration to students' defense of each method.
2. Grouping elements by appearance or color tells us nothing about their chemical behavior or their effects. For example, oxygen in a gaseous form is absorbed by our lungs and stimulates our life processes; chlorine gas, if absorbed by our lungs, is harmful.
3. Symbols are easier to write and are used by scientists in all modern countries. (We hope students will begin to use the symbols for elements instead of full names, but we urge that students not be asked to memorize symbols.)

INQUIRY DEMONSTRATION: Electrostatic Charge

(Teacher Only)

This demonstration introduces students to the study of electrostatic charge. It is designed to raise questions rather than to answer them. Investigation 3.1 provides additional evidence that should help students to formulate reasonable hypotheses about the nature of electrostatic charge. This demonstration is more difficult to perform in areas of high humidity.

MATERIALS

Plastic rulers (6 inch), 3
Paper clips, 2
Masking tape
Piece of plastic wrap (about 8 x 8 inches)
Piece of wool cloth (about 6 x 6 inches)

Most plastic rulers will develop an electric charge when rubbed with wool or plastic wrap. (NOTE: *Clean rulers are essential for success in this demonstration. Wash them with soap and water; rinse and dry thoroughly before each use if you experience any difficulty.*) Before purchasing plastic rulers or using those on hand, test them for insulating ability and for ability to develop a static charge. The type of plastic rods used to demonstrate static electricity are also acceptable. We have selected plastic rulers because students may have seen plastic rods used to demonstrate static charge.

Obtain pure wool rather than cotton or synthetic material. Pieces of cat's fur or sheepskin may be used in place of wool cloth.

Some plastic wraps will not produce a positive charge on rulers. We have found that Saran Wrap and Handi-Wrap give good results.

PROCEDURES

A. Label the rulers *X*, *Y*, and Z. Attach a paper clip to Ruler Y, as shown in Figure T-3 • 2. Bend the clip so that it will support the ruler in an upright position.

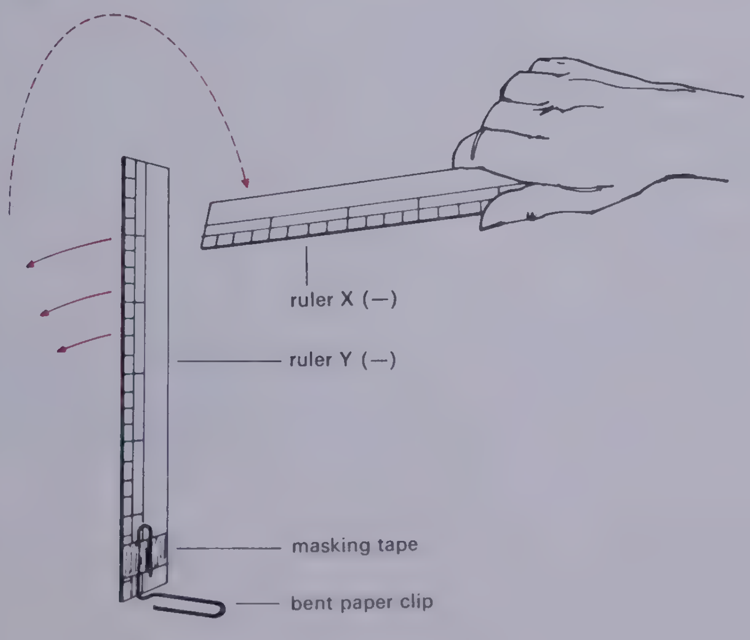


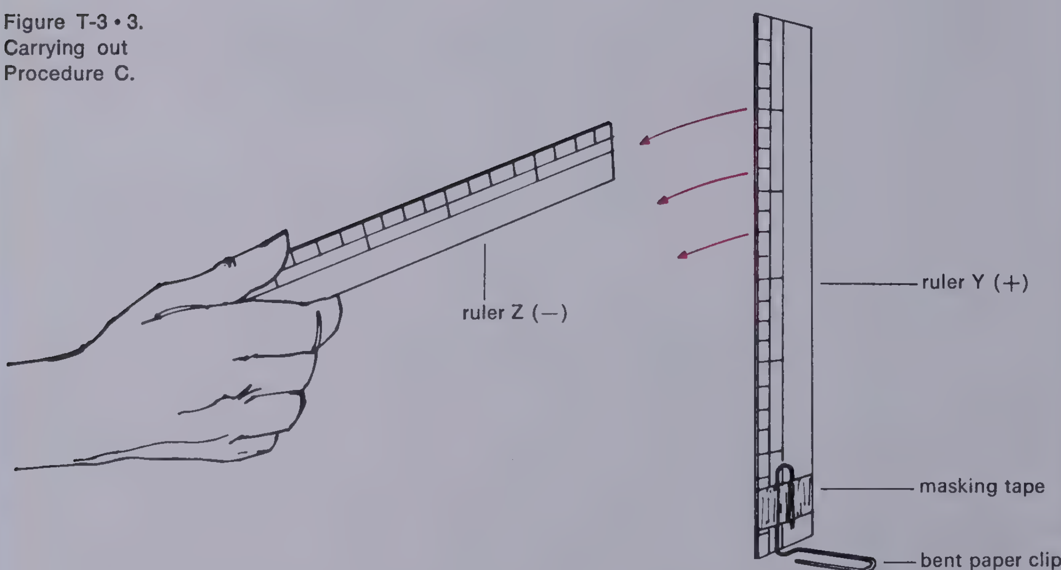
Figure T-3 • 2. Carrying out Procedures A–B.

B. Briskly rub Ruler Y with the wool cloth and place the ruler in an upright position. With cloth, rub Ruler X and hold it about 1 inch from Ruler Y *on the side opposite the paper clip.* There should be no visible reaction. Slowly move Ruler X up and over the top of Ruler Y and down the other side, always keeping the rulers about 1 inch apart. The wool cloth imparts a negative charge to both rulers, so they should repel each other, causing Ruler Y to tip over. Repeat this procedure and invite student comment. Refrain from offering an explanation at this time.

NOTE: *You may wish to rub the rulers behind the desk so that the class cannot see what you are doing.*

C. Rub Ruler Y with *plastic wrap* and place the ruler in an upright position. Rub Ruler Z with the wool cloth. Hold Ruler Z about 1 inch from Ruler Y on the side opposite the paper clip. Since Ruler Y has a positive charge and Ruler Z a negative charge, the rulers should attract each other, causing Ruler Y to tip over (Figure T-3 • 3). Ask for student comment.

Figure T-3 • 3. Carrying out Procedure C.



A few students may suggest that "static electricity" causes the reaction between the rulers. If so, ask them what they mean by the term and emphasize that these words do not explain the reaction—they do not even describe what has happened. Encourage students to interpret their observations. You may want to discuss static electricity after students have completed Investigation 3.1.

If you wish more information on the effects of static electricity, see Rogers[T1] (pp. 535–542), Holton and Roller[T2] (pp. 463–507), or other physics textbooks. We hope this demonstration will start students thinking about the causes of attraction and repulsion. The next investigation provides students with more information useful in developing evidence for the existence of charged particles.

[T1] Eric Rogers, *Physics for the Inquiring Mind* (Princeton, N.J.: Princeton University Press, 1960).

[T2] Gerald Holton and Duane Roller, *Foundations of Modern Physical Science* (Reading, Mass.: Addison-Wesley Publishing Co., 1958).

Grouping Elements by Their Structure and Behavior

Grouping elements by appearance does not give us information about how they behave or react. Sugar and salt may look alike, but you know they do not have the same taste. And under certain conditions the two behave in different ways.

Scientists use behavior as one means of classifying elements. To understand the advantages of this type of classification, you should first investigate some of the ways in which matter behaves.

INVESTIGATION 3.1: Observing Effects of Electrical Charges

Most people have noticed that a spark may be produced when certain materials are rubbed together. You may have heard the crackle of sparks while combing your hair or brushing your dog. You may have received a slight shock from touching a doorknob after walking across a rug. In this investigation you study the effects of such electrical charges on the behavior of matter.

MATERIALS (per team)

Plastic rulers (6- or 12-inch), 2
Ring stand and clamp (or other support)
Thread
Masking tape, 2 small pieces
Piece of wool cloth (6 x 6 inches)
Piece of plastic food wrap (8 x 8 inches)

PROCEDURES

A. Suspend a plastic ruler from the ring stand (Figure 3 • 4). Adjust the thread so the ruler does not touch any other object.
B. Rub both ends of the suspended ruler with wool cloth. Take care not to touch the ends after the ruler has been rubbed. Rub one end of the second ruler with wool and hold it about 1 inch from one end of the suspended ruler. Repeat, using the opposite end of the suspended ruler. Record your observations in your notebook.

C. Repeat Procedure B, but rub *both* rulers with plastic wrap instead of wool cloth. Record your observations.

INTERPRETATIONS

1. How might you account for the behavior of the two rulers after they are rubbed with wool? With plastic wrap?

PROCEDURES

D. Rub both ends of the suspended ruler with wool. Rub one end of the second ruler with plastic wrap. Hold the second ruler about 1 inch from one end of the suspended ruler. Record your observations.

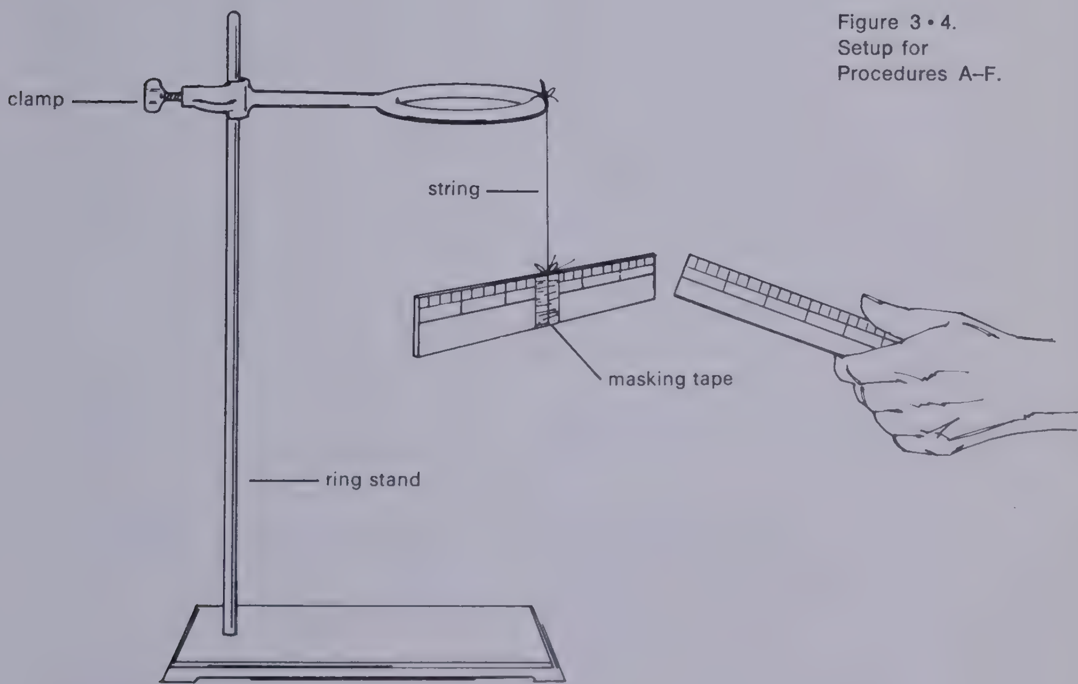


Figure 3 • 4. Setup for Procedures A–F.

INTERPRETATIONS

2. In what way (if any) does the result of Procedure D affect your answer to Interpretation 1?

PROCEDURES

E. Repeat Procedure D, but hold the *plastic wrap* (not the ruler) near one end of the suspended ruler. Sketch and record the result in your notebook.

INTERPRETATIONS

3. Compare the result of Procedure D with that of Procedure E.

PROCEDURES

F. Before carrying out this procedure, read the directions and predict the result. Rub both ends of the suspended ruler with wool. Rub the second ruler with one corner of the wool cloth. Hold that *corner* (not the ruler) near one end of the suspended ruler.

INTERPRETATIONS

4. Were you able to correctly predict the result of Procedure F from the result of Procedure E?

PROBLEM

Construct a model to explain why plastic wrap and wool produce different effects on the rulers. Use the following questions in building your model:

1. Rubbing certain materials together may create static electricity. Is there a relationship between static electricity and the behavior of rulers after they have been rubbed with wool or plastic wrap?
2. If matter contains electricity, where do you think the electricity is located?
3. In Section Two you were introduced to the idea of attraction between particles. Could this idea explain the results of Investigation 3.1? Could a demon theory account for the results of this investigation?

INVESTIGATION 3.1: Observing Effects of Electrical Charges

(pages 60–62)

Students should gain evidence for the existence of two types of electric charge. They should also incorporate the concept of electric charge into their models for the behavior of matter.

MATERIALS

Remember it is advisable to wash the rulers in soapy water; rinse and dry them thoroughly before each use. This is especially critical in humid climates.

PROCEDURES

A. A ring stand is suggested as a convenient support. The thread could be attached to the edge of a desk or lab table, or to a meterstick suspended between two desks. The thread should be attached at the midpoint of the ruler, so the ruler is balanced.

B. When both rulers are rubbed with wool, both are charged negatively and repel each other. If the hand-held ruler is quickly moved back and forth from one end of the suspended ruler to the other, the suspended ruler will oscillate.

   If the hand-held ruler is not moved for several minutes, the suspended ruler will turn until its ends are equidistant from the end of the hand-held ruler.

C. When both rulers are rubbed with plastic wrap, both become positively charged. The repulsion of like charges will give the same results as in Procedure B.

NOTE: *The duration of static charge on an object is influenced by humidity. If the air is humid, rub the rulers frequently.*

INTERPRETATIONS

1. Students might say that rubbing the rulers seems to put something on them that makes them repel each other. Since both procedures give the same results, students will probably suggest that rubbing a plastic ruler with plastic wrap creates the same kind of charge as rubbing it with wool.

PROCEDURES

D. Since the suspended ruler has a negative charge and the hand-held ruler has a positive charge, the rulers will attract each other.

INTERPRETATIONS

2. The students' answers to this depend on their answers to Interpretation 1. They should now be ready to suggest that the behavior of a plastic ruler may depend upon the material used to rub it.

PROCEDURES

E. The plastic wrap should repel the suspended ruler. This evidence can be added to the model of the structure of matter. The handheld plastic ruler acquires a positive charge (as it did in Procedure D), and the plastic wrap acquires an opposite (negative) charge. (The purpose of Procedure E is to make students aware that in the process of rubbing, opposite charges are separated.)

INTERPRETATIONS

3. In Procedure D, the ruler rubbed with wool is attracted by the ruler rubbed with plastic wrap. But the results of Procedure E show that plastic wrap repels the ruler rubbed with wool.

PROCEDURES

F. The wool cloth should attract the suspended ruler. A plastic ruler rubbed with wool acquires a negative charge, so the wool should have acquired a positive charge.

INTERPRETATIONS

4. Most students should have predicted the results correctly. This may be a good time to review what happened during each of the procedures. Make sure that students understand that there is an alternative to the *creation* of the charge: if charge is removed from one object, it may be acquired by another object.

PROBLEMS

1. Students are not expected to design a very specific model. They should recognize that electrical charges are involved and that there are (or appear to be) two kinds of charge. When the same kind of charge is placed on both rulers (when both rulers are rubbed with the same material), the rulers repel each other. When each of the rulers is rubbed with a different material, the rulers attract each other, suggesting that the rulers have been given opposite charges.
2. The possibility that atoms contain bits of electrical charge should be pointed out through class discussion. You may wish to discuss, in some detail, the concept of transferring charged particles from one object to another. The summary of Rutherford's work, which follows, together with the study of static electricity, should

provide the basis for further discussion of the currently accepted atomic model. Encourage students to give their own ideas freely and without fear of ridicule. However, you must help students to arrive at reasonable interpretations and aid them in constructing useful models.

3. The students' model may be based on demons or on the more conventional concept of like and unlike charges. Attempting to determine how one ruler can push another without touching it (the idea of action at a distance) should challenge students. Encourage them to test their model whenever possible.

SUGGESTIONS FOR FURTHER ACTIVITIES WITH STATIC ELECTRICITY

The degree of structure for this activity will depend upon the equipment you have and your students. You may want to put the equipment out and tell them to find out what it does, or you may prefer to give them step-by-step instructions.

Plastic rulers or standard "hard rubber" rods can be used with wool, fur, and plastic wrap to develop static charges. Bits of paper can be picked up. Regular pith balls or homemade devices using nylon thread and Rice Krispies can be used to show transfer of electric charge and electric attraction and repulsion. If you have electroscopes, let students use them. Plastic bags removed from the roll and inflated will often close again due to electrostatic attraction.

The more opportunity students have to investigate static electricity, the better able they should be to incorporate these ideas in their model of the behavior of matter.

If you are familiar with the use of static electric generators such as the Wimshurst machine, the van de Graff generator, and the Kelvin generator, they may be used for demonstrations that are entertaining and instructive. (CAUTION: *Be sure no capacitors, such as Leyden jars, are ever connected to these high voltage generators.*)

The Work of Rutherford

You have seen that the kind of electrical charge placed on two objects determines whether the objects will attract or repel each other. Early in this century, Ernest Rutherford (1871–1937) investigated the electrical properties of matter by studying certain radioactive elements. Atoms of these elements give off tiny *alpha* particles, which travel at extremely high speeds. Alpha particles produce little flashes of light when they strike a specially coated glass plate. This plate can be used as a screen to detect alpha particles.

Rutherford thought that he might learn more about the nature of atoms if he projected a beam of alpha particles toward a very thin layer of matter. Gold is a soft metal and can be hammered into very thin sheets (gold foil). Rutherford placed a sheet of gold foil between his detecting screen and a radioactive source. He saw many little flashes of light on the screen (see Figure 3 • 5). Apparently the alpha particles had passed through the foil.

Rutherford and some of his students observed that most of the particles continued along almost straight paths after passing through the foil. But they also noticed that about one out of every ten thousand particles changed direction as it passed through the foil. The angle of change was often more than 10 degrees. On rare occasions an alpha particle was reflected almost directly backward by the gold foil. This was a surprise. In Rutherford's own words, "It was about as incredible as if you had fired a 15-inch shell at a piece of tissue paper and it came back and hit you."

The following questions and statements are intended to help you understand Rutherford's work. Carefully study each one in order.

1. When two objects (such as two plastic rulers) have like charges, how do the objects affect each other?
2. As you bring two objects with like charges closer together, what happens to the strength of the effect the objects have on one another?

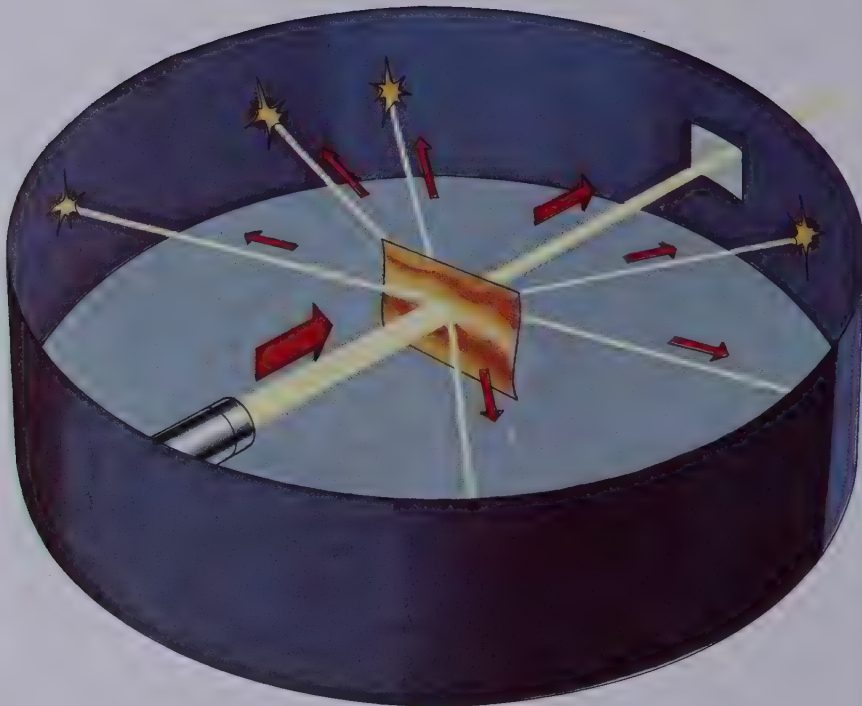


Figure 3 • 5. Diagram of the apparatus Rutherford used to detect the presence of alpha particles. Note that, while the main beam of radiation passes straight through the gold foil, some particles are reflected (bounced back) and some deflected, by the foil.

3. What happens when a charged ruler is held near a very small piece of paper? What happens if the same charged ruler is held near a much larger piece of paper?
4. When alpha particles pass through gold foil, only about one out of every ten thousand particles changes direction. Most of the changes in direction are slight. The direction taken by a few particles changes quite a bit. A very few even bounce back toward the source of radiation. Construct a model for the structure of gold foil that will help explain these observations.

5. Very few of the alpha particles are deflected by the gold foil. But *none* of the gold atoms move. Construct (in your mind) a model of an atom of gold. The model should be as simple as possible; but be sure it is consistent with the observations. Describe your model of an atom of gold.
6. If a beam of negatively charged electrons strikes a piece of tin foil (or gold foil), the foil becomes negatively charged. If a beam of alpha particles strikes tin foil (or gold foil), the foil becomes positively charged. From this information, what kind of charge do you think an alpha particle has?
7. Explain how an atom of gold could be electrically neutral and still affect moving alpha particles.

The Work of Rutherford

(pages 63–65)

The questions and statements are intended to be the basis for class discussion. Guide the students as they develop answers, but encourage them to offer their own ideas.

1. They repel each other. You may wish to demonstrate parts of Investigation 3.1 again.
2. The shorter the distance between the charged objects, the greater their "push" on one another.
3. Prepare some small pieces of paper (a few mm^2) and several larger pieces ranging in size from a few cm^2 to a half sheet of typing paper. Rub a plastic ruler or rod with wool flannel and hold it near each piece of paper. Recharge the ruler when necessary. The small pieces of paper will be attracted to the charged ruler; the larger pieces will not. The small pieces of paper often will pick up the charge from the ruler in a short time and will then be repelled with considerable force.
4. The gold foil is not continuous, that is, it is made up of many particles of varying size and mass. Also the *density* of the particles varies from place to place within the gold foil. Many of the alpha particles might pass through the foil without coming close to a massive particle (a gold nucleus). Those alpha particles which pass near a massive particle are deflected at a slight angle. The closer the alpha particle comes to the gold nucleus, the greater its angle of deflection. An alpha particle that would theoretically hit the nucleus "dead center" would be reflected back toward its source.

   To illustrate the usefulness of this information in adding to the model of atomic structure, ask students to describe why a dozen BB's shot at a peach might behave differently than a dozen BB's shot at a pear. Since the peach has a pit ("nucleus") and a pear has none, the scattering pattern of the two groups of BB's might be different.

   Students will see that this is not an entirely adequate model for the structure of gold foil, but that it does account for some of the observations.
5. Students may make different assumptions here, and these assumptions will affect the construction of their models. If it is assumed that the foil is not gold throughout but is made up of gold particles distributed in space, then the atoms may be viewed as the massive particles. Thus the gold foil might be made up of many tiny but

heavy atoms, separated by distances which are very great in comparison with the diameters of the atoms.

On the other hand, if students assume that the foil is "all gold"—that there is little space in the foil which is not a part of the volume of the atoms—they may visualize a model gold atom having a very heavy central "core" surrounded by a region that is more easily penetrated by the alpha particles.

6. Since the foil struck by the alpha particles becomes positively charged, the charge on the alpha particles must be positive.
7. Have students suggest answers. This way they will feel the model is their own, and not just a "right" answer. If students do need help with this question, you might suggest the following:

   Suppose we assume that an atom of gold is made up of a positively charged center core surrounded by many small, negatively charged particles. Suppose also that the center core is very heavy and that the distances between the smaller particles outside the center core are very great compared with the diameter of the center core. If the total negative charge carried by all of the small bodies outside the core was equal to the total positive charge of the core, the atom would be neutral in charge. The heavy alpha particles would move through the small, scattered, negatively charged bodies with little resistance. Because of the great scattering, very few of the small bodies would be struck by alpha particles. And very few of the massive cores of the gold atoms would be approached closely by the alpha particles. But when an alpha particle did pass near one of these cores, the repulsion of their (like) positive charges would push them apart. Thus the core of a gold atom could deflect an alpha particle without being touched by it.

Discovery of Particles

Early in the 1800's a new atomic theory for the structure of matter was proposed. Atoms were regarded as the basic building blocks of matter. They were thought to be indivisible and without internal structure. By the late 1800's and early 1900's, experiments showed that such a simple model cannot explain the behavior of matter. The existence of particles smaller than atoms was suggested.

The Electron

The *electron*, first of the particles to be discovered, is the lightest of the particles. All electrons have an equal, negative electrical charge.

Most of the volume of an atom is occupied by its electrons. *Only the electrons are transferred in chemical reactions.*

Hundreds of experiments were carried out by many scientists to find out about the properties of electrons. Four men received the Nobel Prize for experiments which greatly contributed to further understanding of electron theory. Philipp E. Lenard of Germany received the Nobel Prize in physics in 1905 for his study of the behavior of charged particles in air. Joseph J. Thomson of England was awarded the Nobel Prize in 1906 for his experiments on the behavior of electrons in a magnetic field. Robert A. Millikan of the United States received the Nobel Prize for physics in 1923 for measuring the charge on electrons. Jean B. Perrin of France was awarded the Nobel Prize in 1926 for his discoveries about the discontinuous structure of matter and for measuring the size of atoms.

The Proton

Next to be discovered was the *proton*. A proton is about 1836 times heavier than an electron. All protons have an equal, positive electrical charge. The simplest atom, hydrogen, has just one proton and one electron. An atom of hydrogen is electrically neutral because its proton's positive charge is equal to its electron's negative charge. Because the proton and the electron have

opposite kinds of charge, they attract each other and stay very close together.

The number of protons in an atom is the factor that makes one element different from another. Every atom of hydrogen has only one proton. There are ninety-two protons in every atom of the heaviest natural element, uranium. Figure 3 • 6 shows the number of protons per atom for some of the more common elements.

Figure 3 • 6. Protons in the atoms of some common elements.

	Carbon	*Nitrogen*	*Oxygen*	*Aluminum*	*Sulfur*	*Iron*	*Gold*
Number of protons per atom	6	7	8	13	16	26	79

The number of protons in one atom of an element is the *atomic number* of that element. Each element has a different atomic number. An element has been identified for every atomic number up to 103. The elements with atomic numbers from 1 to 92 occur in nature. The other eleven have been made by man. Elements with more than 103 protons per atom will probably be produced in the future. But the higher the atomic number, the more difficult (and expensive) the element is to produce.

Ernest Rutherford's work with alpha particles showed that protons are not scattered throughout the atom, but are concentrated in a very small region called the *nucleus*.

The Neutron

In 1932, another kind of atomic particle was discovered—the *neutron* (for neutral particle). A neutron is just as heavy as a proton, but it is electrically neutral. The nuclei of all atoms except those of hydrogen are made up of tightly packed protons and neutrons. The nucleus of a hydrogen atom contains no neutrons and only one proton.

Atomic Weight

If we use one proton (or neutron) as a unit of weight, we can say that the sum of the number of protons and neutrons in an atom is equal to the weight of that atom. A hydrogen atom, for example, has only one proton, so its weight is 1. A helium atom, with two protons and two neutrons, has a weight of 4.

All atoms of an element must have the same number of protons, but the number of neutrons may vary. For this reason atoms of the same element may have different weights. A chemist deals with large numbers of atoms at a time. Therefore, he is not usually interested in the weight of any one atom—but in the average weight of atoms for each element. This average is called the *atomic weight of the element.*

Figure 3 • 7. Summary of atomic particles.

	Proton	*Neutron*	*Electron*
Comparative weight of particles	1	1	$\frac{1}{1836}$
Electric charge of one particle	+1	0	−1
Location	Nucleus	Nucleus	Outside the nucleus
Transferred in chemical change	No	No	Yes

PROBLEMS

1. Must all atoms of the same element have the same weight? Give reasons for your answer.
2. What is the weight and the atomic number of an atom having four protons and five neutrons?
3. An atom of sodium has eleven protons and a weight of 23. What is the atomic number of the sodium atom? How many neutrons does the sodium atom have?

Discovery of Particles

(pages 66–68)

There are many kinds of subatomic particles. We limit discussion to the three most significant in the study of chemistry. Physicists work with many other particles, and a physics class seems the proper place to study them.

When electrical imbalance is created in atoms, charged particles called *ions* are formed. The study of ionization energy (the amount of energy needed to remove an electron from an atom) plays a key role in grouping the electrons for any element. If electrons are being removed from an atom one at a time, a sudden increase in the amount of energy required to remove one more electron indicates that the electron belongs to a new group—a group more tightly bound to the nucleus. This concept is the basis for grouping elements into families in the periodic table. It is also used in the model of atomic structure to determine the number of electrons in each shell, or orbit.

PROBLEMS

1. An element is identified by the number of protons in an atom of that element. Atoms of the same element may have different numbers of neutrons. When this is the case, their weights are different. Atoms of an element having the same number of protons but different numbers of neutrons are *isotopes* of that element.
2. The atomic number of an element is equal to the number of protons —in this case, four. The weight of an atom is the sum of the number of the protons and neutrons—in this case four plus five, or nine.
3. The atomic number of sodium is 11. This isotope of sodium has twenty-three minus eleven, or twelve, neutrons.

NOTE: *Students may ask how an atom can be weighed. It is impossible to "weigh" a single atom in the usual sense of the term. To determine the weight of an atom, it is necessary to weigh a reasonably sized sample of the element, prepared so that the number of atoms present can be calculated. The total weight is then divided by the number of atoms present. You may find it useful to refer back to the method of measuring the thickness of a sheet of paper (page 35). One convenient way to calculate the number of atoms in a sample is to deposit the substance by means of an electric current (electrodeposition), carefully measuring the current and the time during which it flows. An explanation of this method can be found in most physics and chemistry texts, for students who wish to pursue the subject further.*

Electrical Charge of Atoms

An atom must have an equal number of electrons and protons to be electrically neutral. For example, an atom of aluminum (atomic number 13) has thirteen protons. To be neutral, it must also have thirteen electrons. If some of the electrons are removed, the atom will have more protons than electrons. It will have a positive charge.

During Investigation 3.1 you may have observed that the plastic rulers did not remain permanently charged. They gradually became neutral. An atom may become negatively charged by gaining electrons. If this happens, the atom will then return to the neutral state by giving off the extra electrons to its surroundings. In Investigation 3.1 the wool lost electrons to the plastic ruler as a result of the physical process of rubbing. Then the plastic ruler gradually lost the extra electrons to its surroundings (perhaps to the air). The wool regained its lost electrons (perhaps from the air). Whenever a physical process (in this case, rubbing plastic and wool together) produces charges on two different objects, one object will be positively charged, the other negatively charged. If the two objects are brought together again in such a way that electrons can move from one to the other, the two objects will become neutral.

Experiments in which electrons are removed from neutral atoms yield valuable information. Three electrons can be removed from aluminum (atomic number 13) rather easily. However, removal of a fourth electron is very difficult. Only two electrons can be removed easily from magnesium (atomic number 12). If all electrons are removed, one at a time, from atoms of these elements, it becomes evident that there are three groups of electrons in each atom. In an aluminum atom the easiest group to remove contains three electrons. The next group contains eight electrons. And the group most difficult to remove contains two electrons. From this information it is possible to construct a model of the aluminum atom.

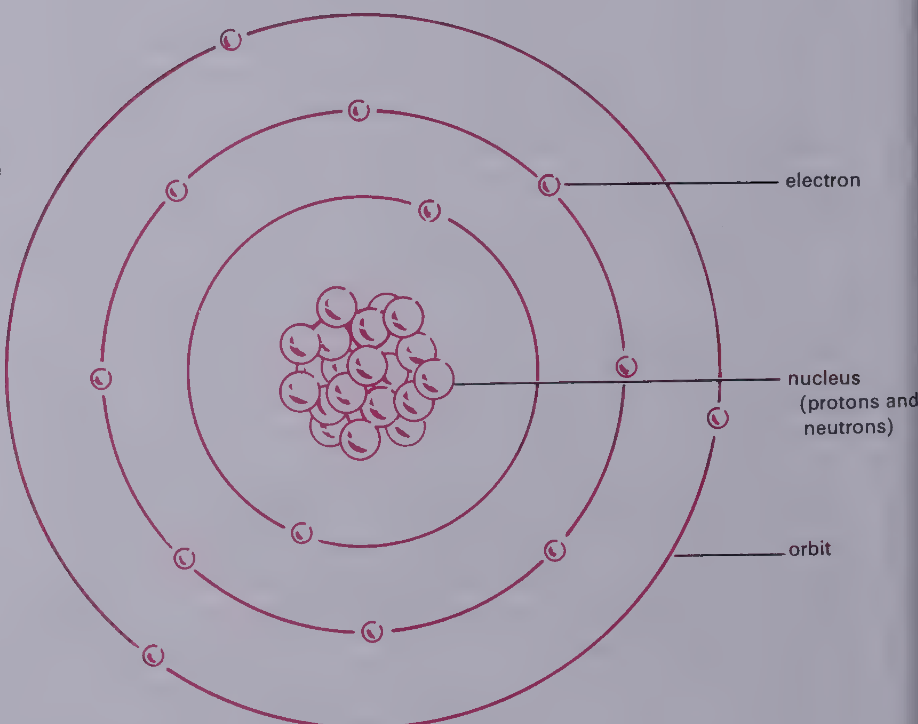
Changing Models of Atomic Structure

Approximately forty years ago a relatively simple atomic model would have accounted for most of the facts then known about atoms. According to this model, electrons moved in definite orbits around the heavier nucleus.

Figures 3 • 8 and 3 • 9 illustrate planetary models of an aluminum atom, with the heavy nucleus (protons and neutrons) surrounded by orbiting electrons. The drawings show a total of thirteen electrons distributed in three orbits: two electrons in the inner orbit, eight in the middle orbit, and three in the outer orbit.

The planetary model of an atom was an attempt to explain the behavior of atoms in a simple way, by comparing their structures to the easily visualized (and accepted) structure of our solar system. It now appears that electrons do not follow fixed paths about

Figure 3 • 8. Drawing of a planetary model of an aluminum atom. According to this model, the electrons travel in fixed paths.



the nucleus. Many kinds of chemical activity could be explained by using this planetary model. But some reactions did *not* fit the model, so changes were necessary.

It is not our intention to make a complete study of the most modern and complex atomic model. Instead, a simplified version of an atomic model may help you to understand some of the basic principles of chemical activity. This model is somewhat more useful, yet no more complex, than the planetary model.

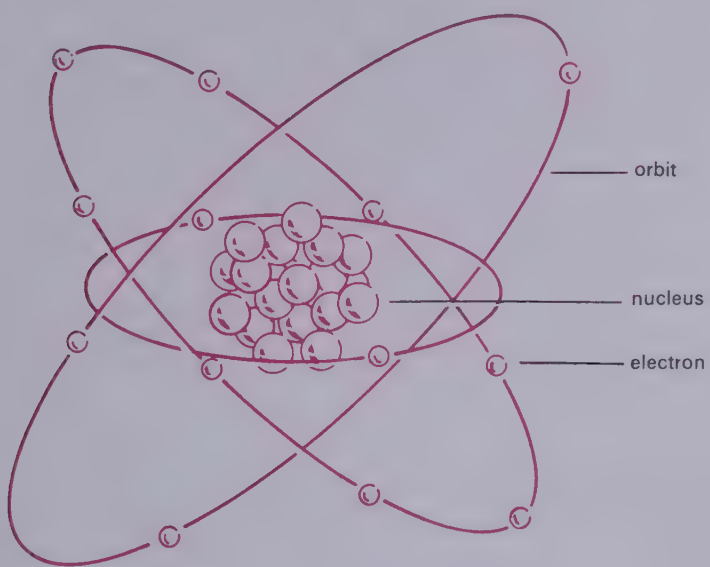


Figure 3 • 9. Drawing of a three-dimensional model of an aluminum atom, in which the electrons orbit in different planes.

Figures 3 • 10 and 3 • 11 show models of the same kind of atom. The grouping of electrons is similar in the two models. But the electron cloud model does not show specific electron paths, or orbits, around the nucleus. Instead, the groups of electrons are pictured as clouds of negative charge. The electrons do not orbit around the nucleus on fixed paths. They occur in several distinct regions, and they are held in the regions by the attraction of the nucleus. The larger the region occupied by the electrons, the easier they are to remove from the atoms. Thus the three electrons in an aluminum atom's outer cloud are more easily removed by chemical activity than are electrons in the two inner clouds.

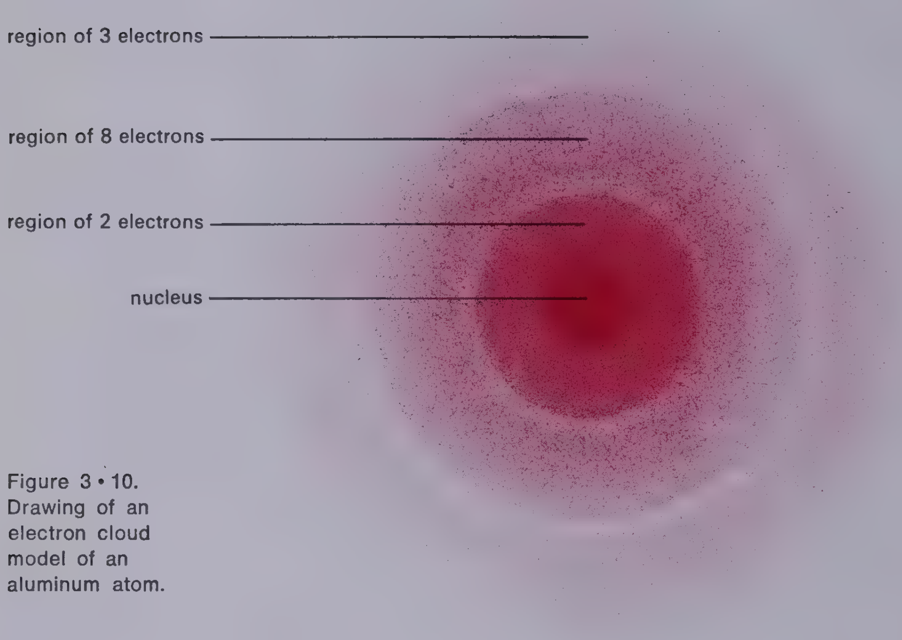
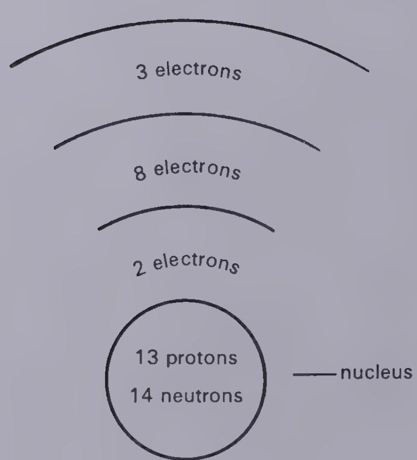


Figure 3 • 10.
Drawing of an electron cloud model of an aluminum atom.

Figure 3 • 11.
Drawing of a simplified model of an aluminum atom.



For convenience we may illustrate this model in a simpler form, as in Figure 3 • 11.

When a transfer of electrical charge results from a physical process, there must be a source of energy. In Investigation 3.1 *you* were the source of energy that produced the separation of charge. You started with two neutral objects and rubbed them together. When you finished, one was negative and the other was positive. A chemical reaction also involves a rearrangement of charge. Some chemical reactions do not require an outside source of energy. Others require a small amount of energy to start and then produce a great deal of energy as they continue. The combining of iron and oxygen to produce rust is a familiar example of a reaction that needs no outside source of energy to begin. As another example, a small amount of energy is required to start a fire. The fire then releases a great deal of energy until the fuel is used up. Surely all of the heat and light from a campfire is not stored in the match that starts it!

To help you understand how chemical reactions occur, we might divide elements into two categories—metals and nonmetals. Atoms of some elements hold their electrons very tightly, while others do not. Nonmetals hold on to electrons tightly. Sulfur and iodine are examples of nonmetals.

Atoms of metals have only a weak attraction for their outer electrons. Aluminum and copper are common elements classified as metals.

A basic difference between metals and nonmetals seems to be that electrons can be removed rather easily from metals, while nonmetals tend to gain and keep electrons.

A large number of chemical reactions involve the combination of a metal and a nonmetal.

Changing Models of Atomic Structure

(pages 70–73)

The modern view of atomic structure does not depict an electron as a particle moving along a path. Instead it considers the probability of finding an electron at any particular distance and direction from the nucleus. To understand the modern (quantum-mechanical) model requires a relatively high degree of mathematical skill. We find it unsatisfactory at this level to regard the electron as a little ball of charge, moving from place to place.

Although the text presents two complementary models to "explain" all the properties of an atom, some properties can be explained with the orbital model alone. Most students need a physical model of an atom and have neither the mathematical nor the philosophical background required for acceptance of a purely mathematical model.

It is important that the electron clouds be described as regions in which the electrons might normally be found. All electrons in a region have approximately the same energy; but those in one region have an energy level quite different from that of electrons in other regions.

Electrons with a high-energy level need to absorb only a little more energy to escape from the nucleus. Electrons closest to the nucleus experience the greatest attraction to it and are the most difficult to remove. Therefore, electrons in the outer cloud are the easiest to remove, and those in the inner cloud are the most tightly bound to the nucleus. To illustrate this by analogy, ask students to imagine marbles rolling in a bowl. A marble near the outer edge will fall out with only slight, additional movement of the bowl. A more vigorous movement will be required to dislodge a marble near the center of the bowl. Encourage students to try this at home. Demonstrating this to the class might stimulate the students' interest in adding to their atomic model.

INQUIRY DEMONSTRATION: Electron Transfer in a Chemical Reaction

(Teacher Only)

This demonstration has two purposes: (1) to provide observable evidence for the transfer of electric charge during a chemical reaction, and (2) to introduce the next investigation, which attempts to establish the existence of ions with negative charge.

You will be demonstrating a primitive electrochemical cell that operates in a manner similar to those in an automobile battery. This demonstration cell has a very small voltage and current capability. Therefore, it is necessary to use a sensitive meter with a full-scale deflection of 1 milliampere.

MATERIALS

Potassium iodide (KI), 2 g
Distilled water, 150 ml
Dialysis tubing (6 inches)
Beaker, 250 ml, or small jar of equivalent size
Paper clips, 2
Bell wire, 2 lengths (10 inch)
Milliammeter (1 milliampere, full-scale deflection)
Iodine crystals (I_2), 2 g

PROCEDURES

A. Dissolve 2 g of potassium iodide (KI) in 150 ml of distilled water. Close off one end of the dialysis tubing by tying it into a knot. Place the dialysis tubing in a 250-ml beaker or jar. Pour potassium iodide solution into the beaker and into the tubing until both are half full. See Figure T-3 • 4.

B. Unfold two paper clips so that their lengths are doubled. Cut away the insulation from both ends of each piece of bell wire. Prepare two paper clip electrodes by connecting a length of wire to one end of each clip. Place one clip in the beaker and the other in the dialysis tubing, so that each is immersed in the KI solution.

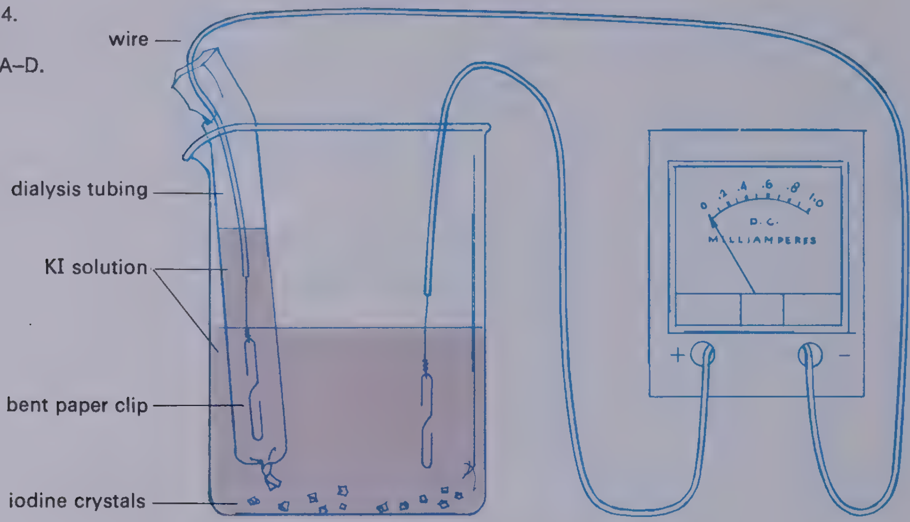
C. Connect the wire from the dialysis tubing to the negative side of the milliammeter. Connect the wire from the beaker to the positive side of the meter. See Figure T-3 • 4.

D. Carefully add 2 g of iodine crystals to the KI solution in the beaker. Observe the brown color as the iodine crystals dissolve in the KI solution. If the paper clip is moved into a brown colored region, a movement of the milliammeter needle should occur.

The electron flow in the reaction might be summarized as follows: two electrons are removed from a neutral atom of iron in the paper clip and are transferred to an iodine molecule (I_2), producing two iodide (I^-) ions.

The transfer of electrons from a metal to a nonmetal demonstrates the difference between these two types of substances. Iron is a good conductor of electricity. When iron is involved in a chemical reaction, atoms of iron (e.g., the paper clip) will lose electrons. Each atom of iron then has more protons than electrons and is called a positive ion.

Figure T-3 • 4. Setup for Procedures A–D.



The iron ions become part of the solution.

The electrons lost by the iron travel through the paper clip, wire, and meter, to the electrical conductor near the iodine. Iodine, a nonmetal, has a strong attraction for electrons. As iodine atoms bump into the conductor, some of them gain electrons, to become negative ions.

Students may not be able to explain the current flow in these terms. They should, however, recognize that a chemical reaction between a metal and a nonmetal has resulted in a flow of electricity through the meter. Encourage students to explain the reaction in terms of a movement of electrons and the formation of ions.

ALTERNATE PROCEDURE

Dialysis tubing forms a good semipermeable membrane. It separates the two solutions and allows the transfer of electric charge through the meter, rather than through direct interaction of atoms in the iodine and in the paper clip. If you do not have dialysis tubing, a second beaker and a piece of Kleenex (or other porous paper) may be substituted, as shown in Figure T-3 • 5. Divide the solution of KI between the two beakers. Fold the Kleenex until it is about 2 cm wide. Put the beakers side by side. Immerse the Kleenex in one beaker; then lift one end out of the solution and place it about halfway into the other beaker (see Figure T-3 • 5). Put an electrode in each beaker and connect the free ends of the wires to the meter. Place crystals of iodine in the beaker

containing the wire that is connected to the positive side of the meter. The current will be less than with dialysis tubing and will build up more slowly, but the apparatus will demonstrate the transfer of charge in a chemical reaction.

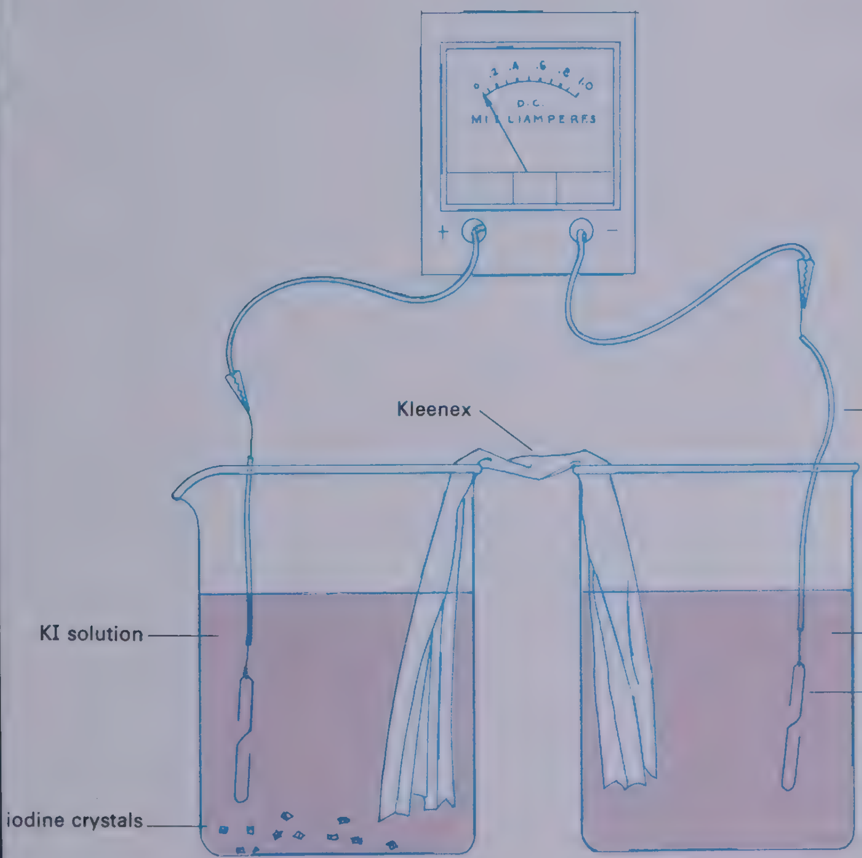


Figure T-3 • 5. Setup for Alternate Procedure.

INVESTIGATION 3.2: Charged Particles in Solution

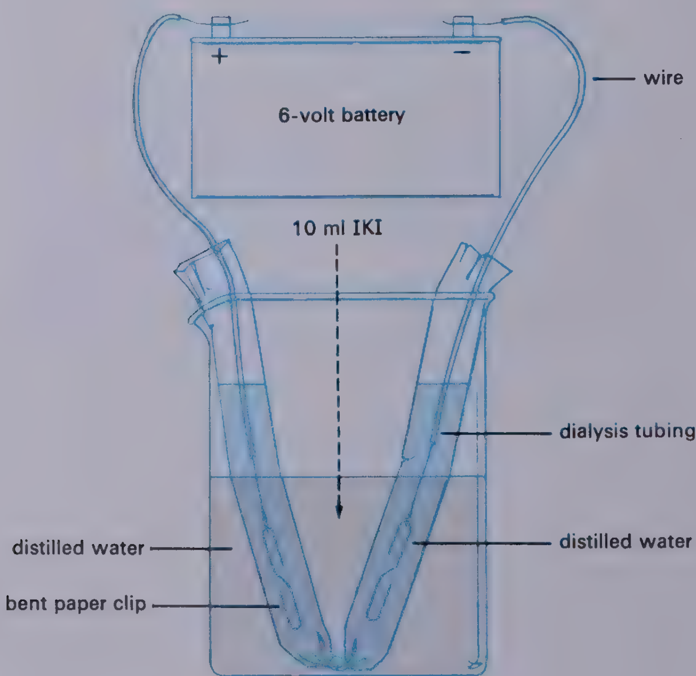
Investigation 3.1 provided evidence that electrons can be added to or removed from some objects. The transfer of electrons results in these objects becoming either positively or negatively charged. If two objects have unlike charges, the objects attract each other. If the charges are the same, the objects repel each other.

During this investigation you study the effect of electricity on particles in solution.

MATERIALS (per team)

- Paper clips, 2
- Bell wire, 2 ten-inch lengths
- Beaker, 250 ml
- Distilled water, 150 ml
- Dialysis tubing, 12-inch length
- 6-volt battery
- Iodine–potassium iodide solution (IKI), 10 ml

Figure 3 • 12. Setup for Procedures A–D.



PROCEDURES

Set up the apparatus shown in Figure 3 • 12 as follows:

A. Unfold two paper clips so their lengths are doubled. Remove the insulation from both ends of each bell wire. Fasten a wire to one end of each unfolded paper clip.

B. Half fill a beaker with distilled water. Moisten the dialysis tubing and tie a knot in the middle of it. Hold up the ends of the tubing and fill each half with distilled water to a depth of about 4 inches. Carefully lower the dialysis tubing into the beaker of water and fold the free ends of the tubing over the edge. Insert a paper clip electrode into the water in each half of the tubing. Attach the free ends of the wires to the battery.

NOTE: *Electricity from the battery will supply electrons to one paper clip and remove electrons from the other. Thus one paper clip will have excess electrons and be negatively charged, while the other will be positively charged.*

C. Add 10 ml of the brown colored IKI solution to the water in the beaker. Allow the paper clips to remain connected to the battery for about twenty minutes.

D. Mark or label each end of the tubing with a + (positive) or − (negative) sign to match the poles on the battery. Disconnect the battery and remove the electrodes from the tubing. Lift the tubing out of the beaker and observe any changes that may have occurred in either half.

INTERPRETATIONS

1. What happened to the water in the tubing that was connected to the positive side of the battery? What happened on the negative side?
2. Do you think that particles of the IKI solution have a positive charge or a negative charge?
3. From the results of this investigation, what evidence do you have that—
   a. neutral atoms might lose electrons and become positively charged?
   b. neutral atoms might gain electrons and become negatively charged?

INVESTIGATION 3.2: Charged Particles in Solution

(pages 74–75)

The purpose of this investigation is to give students some evidence that negative ions exist in solution. Experience indicates that students can understand how a positive ion might be formed when electrons are taken away from a neutral atom. Apparently they have some difficulty in understanding that an electrically neutral atom might attract an electron and become negative.

MATERIALS

The ion used in this investigation is formed with a solution of potassium iodide (containing I^- ions) and crystals of iodine (I_2). This solution has a brown color because of the presence of I^-_3 ions. These negative ions will migrate toward the positive electrode (paper clip connected to the positive side of the battery) and will be repelled by the negative electrode (paper clip connected to the negative side of the battery).

The water in the dialysis tubing (or beaker) containing the negative electrode will remain clear. The water in the dialysis tubing (or beaker) containing the positive electrode will become brown because the positive electrode attracts the negatively charged I^-_3 ions.

It is important that the ion be colored so that its selective migration can be observed and that the ion which was separated be identified with an ion in the original solution. You might try additional substances to show the selective migration of ions toward a source of electrical charge that is opposite the charge of the ion. You should test in advance any substances to be assigned to students for further investigation. For example, solutions containing cobalt ions (Co^{+2}) are pink, and these ions will show selective migration toward the negative electrode. However, if you choose cobalt chloride ($CoCl_2$) as a source of cobalt ions, you will have not only cobalt ions in solution, but also complex negatively charged ions made up of cobalt and chlorine. The latter ions will migrate to a positive electrode and produce a blue precipitate. This might be a challenging problem for bright students to investigate.

Since an investigation of copper sulfate constitutes a major portion of this book, it would be better not to introduce copper compounds at this time.

PROCEDURES

A. It is vital that the wires make good electrical contact with the

paper clips. If you use enameled or varnished wire, remove the insulating finish from the ends of the wire by rubbing them with steel wool.

B. The knot in the dialysis tubing should be tight enough to prevent the flow of solution from one side to the other. The paper clips should be separated from each other as much as possible, and each should be in the center of the tubing, rather than against the wall of the tube.

C. Be sure that enough iodine solution is added so that the resulting solution is brown in color rather than yellow or light orange.

D. Students may notice some bubbles forming on the paper clips. These result from the electrolysis of water. Caution the students about the danger of spilling the brown solution on papers, tabletops, or themselves. The stain is difficult to remove from some materials.

INTERPRETATIONS

1. Water in the part of the tubing connected to the positive side of the battery should turn a brown color. No change should be seen in the part of the tubing connected to the negative side.
2. Since particles of the brown solution passed through the tubing membrane and surrounded the positive electrode, the particles must have acquired a negative charge.
3. *a.* There was no evidence that positively charged particles were formed.

   b. The brown colored particles must have had a negative charge to be attracted by the positively charged paper clip. According to the model of atomic structure, an atom has an equal number of positive and negative charges. To have a negative charge, the particle must have more electrons than protons. This could result if a neutral atom of iodine attracted an electron when the potassium iodide was formed.

INVESTIGATION 3.3: Behavior of Charged Particles in Solution

What happens when two solutions containing both positively and negatively charged particles are mixed? Will all of the charged particles remain in solution? Will some of the particles attract each other enough to join and form new compounds? Will the original chemicals remain unchanged after evaporation removes the water? You may be able to find answers to some of these questions by doing this investigation.

MATERIALS (per team)

- Burner (alcohol or Bunsen), 1
- Beakers (150 ml), 2
- Microscope slides, 4
- Wire gauze
- Funnel
- Medicine droppers, 3
- Test tubes, 2
- Filter paper
- Distilled water, 200 ml
- Potassium iodide, 3 g
- Lead nitrate, 3 g
- Matches
- Masking tape labels

PROCEDURES

A. Pour about 100 ml of distilled water into each beaker. Using a medicine dropper, place one small drop of distilled water near the end of a microscope slide. Put the slide aside for use at a later time.

B. Label one beaker *potassium iodide*. Add the 3 g of potassium iodide to the water in the beaker and stir the solution with a clean medicine dropper. Leave the dropper in the beaker.

C. Label the other beaker *lead nitrate*. (CAUTION: *Lead nitrate is a poison. Be careful not to spill it. If you get some on yourself, wash it off with water and tell your teacher immediately.*)

Add the 3 g of lead nitrate to the water in the beaker and

stir the solution with a clean dropper. Leave the dropper in the beaker.

D. Light the burner as instructed by your teacher and adjust it for a small flame. Hold the microscope slide you prepared in Procedure A by the end farthest from the water drop. Gently warm the water drop over the flame until the liquid has just boiled away; then place the slide on the wire gauze. (CAUTION: *Remember that the glass may stay hot enough for several minutes to burn your fingers.*) Record its appearance.

E. When the potassium iodide has completely dissolved, place a small drop of it near the end of another glass slide and gently warm it until the liquid has just boiled away. Place the slide on the wire gauze. Record the appearance of the slide.

F. When the lead nitrate has completely dissolved, place a small drop of it near the end of another slide and gently warm it until the liquid has just boiled away. Place it carefully on the wire gauze and record its appearance. Turn off the burner.

INTERPRETATIONS

1. Do particles move more freely in a solid than they do when they are dissolved in water?

PROCEDURES

G. Put ten drops of potassium iodide in a test tube. Add ten drops of lead nitrate to the test tube. In your notebook record the appearance of the mixture.

INTERPRETATIONS

2. Copy Figure 3 • 13 in your notebook and answer the questions.

Could *the Substance Produced in Procedure G Be—*	*(Yes or No)*	*What Reason Supports Your Answer?*
Lead nitrate?		
Potassium iodide?		
Distilled water?		
Lead iodide?		
Potassium nitrate?		

Figure 3 • 13.

PROCEDURES

H. Pour the contents of the test tube from Procedure G into a funnel lined with filter paper and catch the liquid in another test tube. Record the appearance of the filtered liquid in your notebook.

INTERPRETATIONS

3. Do you see any evidence of charged particles in the filtered liquid?
4. Do you think that the filtered liquid might contain any charged particles?

PROCEDURES

I. Use a *clean* medicine dropper to put a drop of the filtered liquid near the end of a glass slide. Light the burner and adjust it for a small flame. Gently warm the drop until the liquid has just boiled away. Immediately place the glass slide on the wire gauze and turn off the burner. Observe and record the appearance of the slide.

INTERPRETATIONS

5. Lead and potassium are positively charged particles. Iodide and nitrate are negatively charged particles. Copy Figure 3 • 14 in your notebook and answer the questions.

Figure 3 • 14.

Could the New Substance You Saw Formed Be a Combination of—	*(Yes or No)*	*What Reason Supports Your Answer?*
Lead and potassium?		
Iodide and nitrate?		
Lead and iodide?		
Lead and nitrate?		
Potassium and nitrate?		
Potassium and iodide?		

6. Potassium nitrate is a white solid. What is the name of the new substance that formed when lead nitrate and potassium iodide solutions were mixed?
7. Describe how an atomic model of matter or a demon model could explain the results of this investigation.

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INVESTIGATION 3.3: Behavior of Charged Particles in Solution

(pages 76–79)

Students should learn that positively and negatively charged particles in solution are free to move separately and may form new combinations when solutions are mixed. If your students have only limited experience in the laboratory, you may need to spend class time discussing and demonstrating techniques such as the use of burners and filtration.

MATERIALS

You may find it will save time and the possibility of contamination of reagent containers if you provide preweighed solid samples.

PROCEDURES

A. Be sure students use distilled water and not tap water. The latter may contain enough chloride to give a precipitate with lead nitrate and will leave a residue when evaporated in Procedure D.

B. Dropper bulbs often become contaminated, especially if several classes repeat the investigation in the course of a day. If there is any doubt about the cleanliness of the dropper, students should rinse the bulbs and the tubes with distilled water.

C. The caution for Procedure B applies here, too. Lead nitrate is a poison. Caution students not to touch the solid or the solution.

D. Caution students about heat from the burner. Best results are obtained from a small flame. Students may need instruction on adjusting the burner. Remind them that glass stays hot for several minutes after it is heated. Results: there should be no residue after the liquid has boiled away.

E. A white residue should remain after the liquid has boiled away.

F. Remind students to turn off the burner. A white residue should remain after the liquid has boiled away.

INTERPRETATIONS

1. Particles have more freedom to move when dissolved in water. (Since the drops that were evaporated contained solid material, it is reasonable to suppose that every drop in the solution contains some of the dissolved material.)

PROCEDURES

G. A yellow, solid precipitate forms in the test tube.

INTERPRETATIONS

2. Answers should resemble those in Figure T-3 • 6.

Figure T-3 • 6.

Could the Substance Produced in Procedure G be—	*(Yes or No)*	*What Reason Supports Your Answer?*
Lead nitrate?	No	It is white, not yellow.
Potassium iodide?	No	It is white, not yellow.
Distilled water?	No	It is colorless, not yellow.
Lead iodide?	Yes	It would be a new combination of ions.
Potassium nitrate?	Yes	It would be a new combination of ions.

PROCEDURES

H. You may need to show students how to fold filter paper for use in a funnel. The filtered solution should be clear and colorless.

INTERPRETATIONS

3. No evidence of charged particles in solution is visible.
4. Answers will vary, since an opinion is called for.

PROCEDURES

I. A white, solid residue remains after the liquid has boiled away.

INTERPRETATIONS

5. Answers should resemble those in Figure T-3 • 7.

Figure T-3 • 7.

Could the New Substance You Saw Formed Be a Combination of—	*(Yes or No)*	*What Reason Supports Your Answer?*
Lead and potassium?	No	Positive charges repel each other.
Iodide and nitrate?	No	Negative charges repel each other.
Lead and iodide?	Yes	It would be a new combination of charged particles.
Lead and nitrate?	No	Lead and nitrate existed in a clear solution.
Potassium and nitrate?	Yes	It would be a new combination of particles.
Potassium and iodide?	No	Potassium and iodide existed in a clear solution.

6. The yellow substance was lead iodide.
7. Structure of matter model: oppositely charged particles may attract each other enough to join together and drop out of solution. Demon model: some kinds of demons are attracted to each other so much that they force thin atoms to form a precipitate.

SUPPLEMENTARY MATERIALS

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FILMS

Copper, The Oldest Metal. Bureau of Mines Film #256. 27 minutes. Color. This film shows where metals are found and how they are put to use. Copper was one of the first metals to be used by man.

FILM LOOP

Investigating Chemical Families. Interaction Film Loops, Inquiry in Physical Science, Rand McNally & Co.

SUGGESTED ACTIVITIES FOR TESTING LABORATORY SKILLS AND TECHNIQUES

INVESTIGATION 3.2

Tie off dialysis tubing and add water to the tubing.

INVESTIGATION 3.2

Remove insulation from bell wire and attach the wire to a specified pole of a battery.

SECTION FOUR

Classification of the Elements: Refining a Model

SECTION FOUR

Classification of the Elements: Refining a Model

(pages 81–104)

Preview

Learning to organize information to make it more useful is an important scientific skill. For this reason, classification of the elements is the major goal of Section Four.

In Section Three, students were given a list of eighteen elements together with their chemical symbols and a brief description of each element. They then grouped these eighteen elements according to their appearance.

In this section, with the same information plus the atomic number and the number of electrons that could be either gained or lost by each element during a chemical reaction, students group the same eighteen elements in order of increasing atomic number and the number of electrons gained or lost.

Students should see a pattern in the loss or gain of elements and then prepare a chart that reflects this pattern and that also keeps the elements in order of increasing atomic number. Students will thus have constructed a partial periodic chart for the first eighteen elements.

NOTE: *Some students may have difficulty in constructing the two charts and will need your assistance. We suggest that you allow them time to "do it on their own" and give assistance only when students become discouraged.*

Nine families of elements appear in chart form. Each family includes the names of the elements, their symbols, atomic numbers, atomic weights, and the number of electrons per group. A brief description of each family includes the technological uses of some of the elements in the family.

To help students solve various problems involving the transfer of electrons, a set of practice problems with answers is included. The summary chart on pages 92–93 should prove useful in dealing with these and later problems.

During a discussion of Mendeléeff's chart, it is shown that he predicted the existence of elements not known to exist at that time. This leads directly to a modern partial periodic table of the elements and to Section Five, "Investigating Properties of Chemical Families."

The mole concept is presented as optional material, but we urge you to include it. In Sections Six and Eleven, there are opportunities to apply the mole concept.

There was a time when information about atoms was gained only in chemistry and physics classes. Today, as a result of mass media, many students already have some acquaintance with molecules and atoms. The difficulty, of course, is that all students have not had the same experiences.

A major goal in this course is to aid students in understanding the following concepts:

1. Compared with the volume of its nucleus, the volume of an atom is very large.
2. Electrons are located in the portion of the atom outside the nucleus. They determine the extent of the volume of that atom.
3. The nucleus contains all of an atom's positive charge.
4. The positive charge of the nucleus is contributed by the protons.
5. Almost all of the mass is contained in the nucleus.
6. The weight of an atom is equal to the sum of the number of protons and neutrons in the atom.
7. The atomic number of an element is equal to the number of protons in each atom of that element.
8. Chemistry is concerned with effecting changes in the number of electrons in the outer regions of an atom. Chemical processes cannot affect the nucleus.
9. Properties of elements are determined by the structure of their atoms. Section Four introduces the last two of these concepts and provides a further discussion of the first seven, which were introduced in Section Three.

PLANNING AHEAD

Check the material list for the demonstration to be sure you have the equipment and supplies on hand.

See page 84A for directions on preparing packets of paper squares of various colors.

LEARNING OBJECTIVES

Given the opportunity to inquire, to investigate, to interpret data, and to offer hypotheses about the activities in this section, most students should be able to—

- Sort and classify elements by atomic number;
- Sort and classify elements by the number of electrons gained or lost in reactions;
- Analyze several different classification systems of elements;
- Reevaluate classification systems as the students gain new insight or new information;
- Describe the significance of the *families of elements;*
- Recognize and explain the periodic nature of the atomic chart;
- Explain the production of some new substances that result from chemical reactions;
- Demonstrate an ability to describe chemical reactions with equations and solve reaction problems which involve electron transfers;
- Recognize the tentative nature of scientific interpretation.

When two or more elements *react* (combine), they produce a new substance called a *compound.* In every compound the atoms are bonded (joined together) in a certain way. A molecule of water (formula H_2O) is made up of two atoms of hydrogen joined to one atom of oxygen. There are hundreds of thousands of different compounds, each with its own particular combination of elements. Sugar is made from the elements carbon, hydrogen, and oxygen. Table salt is made from sodium and chlorine.

Experiments during the last one hundred fifty years have provided evidence that elements can be organized into groups according to behavior. Investigations like those you have performed, the work of Rutherford, and many other experiments have been used as evidence that the numbers of protons or electrons in atoms might be the key to classifying elements into groups.

In Section Three you saw evidence that chemical reactions involve the transfer of electrical charge. According to your model of an atom—a small positive nucleus surrounded by negatively charged electrons—the transfer of electric charge is a transfer of electrons from one atom to another. You found that some atoms tend to lose electrons, while other atoms tend to attract and keep electrons.

Your next problem will be to group elements according to their ability to gain or lose electrons. In this way you may be able to predict which of the elements you will study should combine to form compounds.

PROBLEMS

1. Examine Figure 4 • 1 carefully. It is similar to Figure 3 • 2, but it contains additional information. Obtain a set of paper squares of four different colors. Select one color for elements that lose electrons, another for elements that gain electrons, a

Element	Symbol	Description	Atomic Number	Number of Electrons Readily Gained or Lost
Aluminum	Al	silvery metal	13	3 lost
Argon	Ar	colorless gas	18	0 lost or gained
Beryllium	Be	silvery metal	4	2 lost
Boron	B	yellowish brown crystal	5	3 lost
Carbon	C	black crystal	6	4 lost or gained
Chlorine	Cl	yellow green gas	17	1 gained
Fluorine	F	pale yellow gas	9	1 gained
Helium	He	colorless gas	2	0 lost or gained
Hydrogen	H	colorless gas	1	1 lost
Lithium	Li	silvery metal	3	1 lost
Magnesium	Mg	silvery metal	12	2 lost
Neon	Ne	colorless gas	10	0 lost or gained
Nitrogen	N	colorless gas	7	3 gained
Oxygen	O	colorless gas	8	2 gained
Phosphorus	P	red or yellow crystal	15	3 gained
Silicon	Si	silvery crystal	14	4 lost or gained
Sodium	Na	silvery metal	11	1 lost
Sulphur	S	yellow crystal	16	2 gained

Figure 4 • 1. Properties of some elements.

third color for elements that either gain or lose electrons, and a fourth for elements that neither gain nor lose electrons. Use a separate paper square for each element and record three pieces of information. At the top of the square, write the number of electrons the element gains or loses. In the middle of the square write the symbol for the element. At the bottom of the square write its atomic number. For example, if yellow is the color chosen for elements that lose electrons, take a yellow

square for aluminum. The completed square should look like Figure 4 • 2. Make a separate square for each element in Figure 4 • 1. Be sure to use the proper color to indicate how electrons of that element behave.

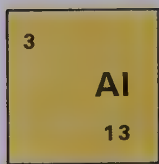


Figure 4 • 2. Sample element square for aluminum.

2. Arrange the squares in a line according to atomic number (the number at the bottom of the square). Start with atomic number 1 on the left and end with atomic number 18 on the right. In your notebook, make a copy of the arrangement of squares.
3. Study the line of squares carefully. What pattern do you see in the numbers of electrons gained and lost?
4. Make a new arrangement of the squares according to atomic number *and* the number of electrons gained and lost. The new arrangement should have several rows instead of just one. Colors will also help in making the new grouping. After your arrangement has been checked by your teacher, copy it in your notebook.

INTERPRETATIONS

1. Pick an element that loses a certain number of electrons and another element that gains the same number of electrons. Suggest at least one compound that could result from a transfer of electrons.
2. Which element would not be likely to combine with anything?
3. Compare the chart you prepared in the problem above with your method of grouping elements in the problem on page 57. Which way of arranging elements is more useful—according to appearance or according to atomic number? Why?

Classification of the Elements: Refining a Model

(pages 82–84)

In this activity, students prepare an abbreviated form of the periodic table based on atomic number and ability to gain or lose electrons.

MATERIALS

You will need one packet of colored paper squares per student. The paper squares should be about 3 × 4 cm each. If students chose their own system of color representation, each packet should contain seven squares each of four colors. If you assign colors, then each packet should contain seven squares representing "lose," six squares for "gain," three for "neither," and two for "gain or lose."

PROBLEMS

1. You may find it helpful to have a sample set of squares made up in advance and arranged alphabetically as in Figure 4 • 1.
2. Some students have difficulty completing the chart. Assist them if necessary, but encourage each student to work on his own. Do *not* permit them to look ahead in their books for aid.

Figure T-4 • 1. Completed chart for Interpretation 2.

1	0	1	2	3	4	3	2	1	0	1	2	3	4	3	2	1	0
H	He	Li	Be	B	C	N	O	F	Ne	Na	Mg	Al	Si	P	S	Cl	Ar
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18

3. Students should notice the following pattern: 1L–2L–3L–4L or G–3G–2G–1G–None L or G, which occurs twice. Discuss this before students copy their new arrangement in their notebooks.
4. Finished charts should be similar to Figure T-4 • 2.

1 H 1							0 He 2
1 Li 3	2 Be 4	3 B 5	4 C 6	3 N 7	2 O 8	1 F 9	0 Ne 10
1 Na 11	2 Mg 12	3 Al 13	4 Si 14	3 P 15	2 S 16	1 Cl 17	0 Ar 18

Figure T-4 • 2.

Students should see that hydrogen and helium must be placed so that the number of electrons gained or lost by each matches the number of electrons gained or lost by other elements in the same column.

INTERPRETATIONS

1. Since they have already been told that metals combine with nonmetals (p. 73) and that sodium and chlorine form a compound (p. 82), students may suggest a number of combinations based on the electrons lost or gained by different elements in the lithium and fluorine "columns." These combinations might include sodium and fluorine, lithium and chlorine, magnesium and oxygen, or any element that loses electrons combined with an element that gains electrons.
2. Their chart should tell them that the elements He, Ne, and Ar will not combine with any element, because these three neither gain nor lose electrons.
3. A chart of elements to be used in chemistry should be based on chemical properties—the tendencies of atoms of an element to gain or lose electrons—rather than on properties related to the physical appearance of the element. The value of any classification system is determined by its usefulness. A classification system based upon the appearance of elements would not be used for predicting chemical activity. If the goal is to predict chemical activity, the new chart is more useful.

OPTIONAL DEMONSTRATION: Magnesium Ribbon

(Teacher Only)

MATERIALS

Magnesium ribbon
Tongs
Bunsen burner

CAUTION: *Before beginning the demonstration, warn students not to look directly at the burning ribbon.*

Hold a piece of magnesium ribbon with tongs and ignite it in the flame of a Bunsen burner.

Ask students to suggest what element combined with the magnesium, and why. They may have some trouble selecting oxygen. But, according to their chart, magnesium readily loses two electrons, and only two elements described thus far—oxygen and sulfur—readily gain two electrons. Since many students know that oxygen is a component of air, they may suggest that oxygen is involved.

Figure 4 • 3.
The *Hindenburg*, 1937, at Lakehurst, N.J. This balloon-like airship was filled with hydrogen gas. From the evidence shown and the information which follows, could hydrogen belong to the helium family? Into which family *would* you place it?

Groups of Elements

There are many useful ways to group elements. The local power company might prefer to group elements according to the ease with which they conduct electricity. The jeweler might want to classify elements according to their ability to resist corrosion. The chemist is interested in the way in which elements combine to form compounds. Groups of elements that exhibit similar behavior when combined with other elements are called *families* of elements. A brief discussion of a few of these families follows.

The Helium Family

With few exceptions, the six gases in the helium family are not involved in chemical reactions. They are therefore called *inert* (unchanging) gases. The members of this family are grouped together because they generally lack the ability to combine among themselves or with elements of other families.

With the exception of radon, the members of the helium family were discovered within the four-year period from 1894 to 1898. Members of this family tend not to react chemically. They are present in very small amounts in the atmosphere, and their discovery depended upon finding some means of isolating them. After it became possible to compress air under great pressure—forming liquid air—these elements were discovered. Elements of

the helium family remain after the oxygen and nitrogen in liquid air are boiled away (Figure 4 • 5).

Since the nucleus of an atom is not directly involved in chemical reactions, the lack of chemical reactivity of the inert gases probably has something to do with the structure of their electron groups. The behavior of members of other chemical families will be a test of this idea.

Figure 4 • 4. Neon gas when electrically excited gives off a red color. Addition of other gases produces other colors.

Figure 4 • 5. The helium family.

Name	*Symbol*	*Atomic Number*	*Atomic Weight*	*Number of Electrons Per Group*					
Helium	He	2	4.0	2					
Neon	Ne	10	20.2	2	8				
Argon	Ar	18	39.9	2	8	8			
Krypton	Kr	36	83.8	2	8	18	8		
Xenon	Xe	54	131.3	2	8	18	18	8	
Radon	Rn	86	222.0	2	8	18	32	18	8

The Fluorine (or Halogen) Family

Unlike the inert gases, fluorine and other members of its family combine readily with many other elements. Though the four elements in the fluorine family are similar in their chemical reactions, they differ considerably in physical appearance. At room temperature fluorine and chlorine are gases, bromine is a liquid, and iodine is a solid. Solutions of iodine are used as antiseptics. Chlorine is used to purify water. Some compounds of fluorine are apparently effective in preventing tooth decay (Figure 4 • 6).

Figure 4 • 6. The fluorine (or halogen) family.

Name	*Symbol*	*Atomic Number*	*Atomic Weight*	*Number of Electrons Per Group*				
Fluorine	F	9	19.0	2	7			
Chlorine	Cl	17	35.5	2	8	7		
Bromine	Br	35	79.9	2	8	18	7	
Iodine	I	53	126.9	2	8	18	18	7

The Oxygen Family

Oxygen is a colorless gas; sulfur is a bright yellow solid. All other members of the oxygen family are silver gray solids.

Each atom of an element in this family has six electrons in its outer group (Figure 4 • 7). Scientists think that chemical activity depends on the number of electrons in the outer group. As a result, the elements in the oxygen family react with hydrogen to produce compounds with similar *formulas*. Chemical formulas are made up of element symbols and numbers that show the quantity of atoms of each element present.

Name	*Symbol*	*Atomic Number*	*Atomic Weight*	*Number of Electrons Per Group*					
Oxygen	O	8	16.0	2	6				
Sulfur	S	16	32.1	2	8	6			
Selenium	Se	34	79.0	2	8	18	6		
Tellurium	Te	52	127.6	2	8	18	18	6	
Polonium	Po	84	210.0	2	8	18	32	18	6

Figure 4 • 7. The oxygen family.

The following are formulas for compounds produced when members of the oxygen family react with hydrogen: H_2O, H_2S, H_2Se, H_2Te, and H_2Po. Though these compounds have similar formulas, they have very different properties (Figure 4 • 8). For instance, H_2O (water) is a substance necessary for life; but the hydrogen compounds formed by other members of the oxygen family are highly poisonous.

	Hydrogen Oxide (Water)	*Hydrogen Sulfide*	*Hydrogen Selenide*	*Hydrogen Telluride*
Formula	H_2O	H_2S	H_2Se	H_2Te
Odor	None	Rotten Eggs	Sour Garlic	Awful
Toxicity	None	Poisonous	Poisonous	Poisonous

Figure 4 • 8. Examples of oxygen family members combined with hydrogen. In what way are the formulas for these compounds similar?

The Nitrogen Family

Each atom of elements in the nitrogen family has five electrons in its outer region (Figure 4 • 9).

Compounds containing nitrogen or phosphorus are found in all living cells. Many compounds containing arsenic have been used as insecticides and weed killers. Antimony and bismuth are metals; they are often mixed with copper to change its hardness or color.

Figure 4 • 9. The nitrogen family.

Name	*Symbol*	*Atomic Number*	*Atomic Weight*	*Number of Electrons Per Group*					
Nitrogen	N	7	14.0	2	5				
Phosphorus	P	15	31.0	2	8	5			
Arsenic	As	33	74.9	2	8	18	5		
Antimony	Sb	51	121.8	2	8	18	18	5	
Bismuth	Bi	83	209.0	2	8	18	32	18	5

The Carbon Family

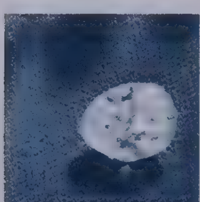
Each atom of elements in the carbon family has an outer group of four electrons. Because they tend either to gain or to lose four electrons, there is great variability among the elements in this family (Figure 4 • 11).

Like nitrogen and phosphorus, carbon is found in all living things. It can form over a hundred thousand different compounds. For example, most of the material that makes up the paper in this book is a compound of carbon. Sugar, fats, gasoline, and plastics are all compounds of carbon. Pure carbon may be black, as it is in soot, or it may form the very hard crystals called *diamonds*.

Silicon is one of the most abundant elements in the earth's crust. Many kinds of sand are compounds of silicon and oxygen. Ordinary garden soil includes many different silicon compounds.

Tin and lead are common metals, but pencil "lead" is a mixture of carbon and clay.

Figure 4 • 10. Diamonds, the hardest natural substance, are prized for their ability to reflect "sparkles" of light.



Name	*Symbol*	*Atomic Number*	*Atomic Weight*	*Number of Electrons Per Group*					
Carbon	C	6	12.0	2	4				
Silicon	Si	14	28.1	2	8	4			
Germanium	Ge	32	72.6	2	8	18	4		
Tin	Sn	50	118.7	2	8	18	18	4	
Lead	Pb	82	207.2	2	8	18	32	18	4

Figure 4 • 11. The carbon family.

The Boron Family

There are three electrons in the outer group of an atom of each element in the boron family (Figure 4 • 13). Boron and aluminum commonly occur in mineral deposits and have many household uses. Other members of the family are very rare.

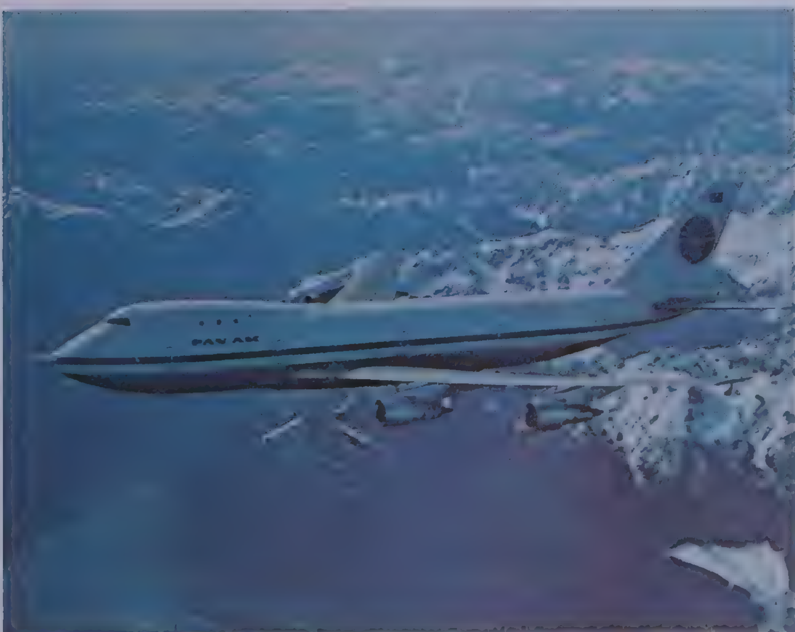


Figure 4 • 12. The use of light aluminum metal in the frame of this 747 increases its capacity to carry fuel and cargo.

You may have heard of borax and boric acid. Borax is a compound of boron, sodium, and oxygen and is often used as a cleaning and deodorizing agent. Boric acid contains boron, hydrogen, and oxygen and is sometimes used as an eyewash.

What would our lives be like without aluminum? Its lightness, strength, and low cost make modern air transportation possible. It is an excellent conductor of electricity, and many power transmission lines are made of aluminum. You may be familiar with its many uses in the home.

Gallium and indium are quite rare, but they are useful in some kinds of materials needed in the electronics industry.

Compounds of thallium have been used in poisons for controlling rodents.

Figure 4 • 13. The boron family.

Name	*Symbol*	*Atomic Number*	*Atomic Weight*	*Number of Electrons Per Group*					
Boron	B	5	10.8	2	3				
Aluminum	Al	13	27.0	2	8	3			
Gallium	Ga	31	69.7	2	8	18	3		
Indium	In	49	114.8	2	8	18	18	3	
Thallium	Tl	81	204.4	2	8	18	32	18	3

The Beryllium Family (Alkaline Earths)

Each atom of an element in the beryllium family has two electrons in its outer region (Figure 4 • 14). These electrons are easily lost to elements that gain electrons. Magnesium and calcium are present in many compounds found in the earth's crust. And both are present in living cells. Limestone is a combination of compounds of calcium, carbon, and oxygen.

In pure form all elements in the beryllium family are metallic in appearance.

Name	Symbol	Atomic Number	Atomic Weight	Number of Electrons Per Group						
Beryllium	Be	4	9.1	2	2					
Magnesium	Mg	12	24.3	2	8	2				
Calcium	Ca	20	40.1	2	8	8	2			
Strontium	Sr	38	87.6	2	8	18	8	2		
Barium	Ba	56	137.4	2	8	18	18	8	2	
Radium	Ra	88	226.0	2	8	18	32	18	8	2

Figure 4 • 14. The beryllium family (alkaline earths).

The Lithium Family

The most common elements in the lithium family are sodium and potassium (Figure 4 • 15). Compounds of sodium and potassium are found in all living cells.

Each atom of an element in this family has only one electron in its outer group. Since this electron is easily removed, these elements are among the most reactive known. In chemical laboratories, pure sodium and potassium are kept in kerosine to prevent them from reacting with oxygen or water in air. In pure form, elements of this family look like typical metals, though they are somewhat softer than the metals used for construction purposes.

Name	Symbol	Atomic Number	Atomic Weight	Number of Electrons Per Group						
Lithium	Li	3	6.9	2	1					
Sodium	Na	11	23.0	2	8	1				
Potassium	K	19	39.1	2	8	8	1			
Rubidium	Rb	37	85.5	2	8	18	8	1		
Cesium	Cs	55	132.9	2	8	18	18	8	1	
Francium	Fr	87	223.0	2	8	18	32	18	8	1

Figure 4 • 15. The lithium family.

Family	*Name*	*Symbol*	*Atomic Number*	*Atomic Weight*	*Number of Electrons Per Group*					
Helium	Helium	He	2	4.0	2					
	Neon	Ne	10	20.2	2	8				
	Argon	Ar	18	39.9	2	8	8			
	Krypton	Kr	36	83.8	2	8	18	8		
	Xenon	Xe	54	131.3	2	8	18	18	8	
	Radon	Rn	86	222.0	2	8	18	32	18	8
Fluorine (or Halogen)	Fluorine	F	9	19.0	2	7				
	Chlorine	Cl	17	35.5	2	8	7			
	Bromine	Br	35	79.9	2	8	18	7		
	Iodine	I	53	126.9	2	8	18	18	7	
Oxygen	Oxygen	O	8	16.0	2	6				
	Sulfur	S	16	32.1	2	8	6			
	Selenium	Se	34	79.0	2	8	18	6		
	Tellurium	Te	52	127.6	2	8	18	18	6	
	Polonium	Po	84	210.0	2	8	18	32	18	6
Nitrogen	Nitrogen	N	7	14.0	2	5				
	Phosphorus	P	15	31.0	2	8	5			
	Arsenic	As	33	74.9	2	8	18	5		
	Antimony	Sb	51	121.8	2	8	18	18	5	
	Bismuth	Bi	83	209.0	2	8	18	32	18	5

	Bismuth	Bi	83	209.0	2	8	18	32	18	5	
Carbon	Carbon	C	6	12.0	2	4					
	Silicon	Si	14	28.1	2	8	4				
	Germanium	Ge	32	72.6	2	8	18	4			
	Tin	Sn	50	118.7	2	8	18	18	4		
	Lead	Pb	82	207.2	2	8	18	32	18	4	
Boron	Boron	B	5	10.8	2	3					
	Aluminum	Al	13	27.0	2	8	3				
	Gallium	Ga	31	69.7	2	8	18	3			
	Indium	In	49	114.8	2	8	18	18	3		
	Thallium	Tl	81	204.4	2	8	18	32	18	3	
Beryllium (Alkaline Earths)	Beryllium	Be	4	9.1	2	2					
	Magnesium	Mg	12	24.3	2	8	2				
	Calcium	Ca	20	40.1	2	8	8	2			
	Strontium	Sr	38	87.6	2	8	18	8	2		
	Barium	Ba	56	137.4	2	8	18	18	8	2	
	Radium	Ra	88	226.0	2	8	18	32	18	8	2
Lithium	Lithium	Li	3	6.9	2	1					
	Sodium	Na	11	23.0	2	8	1				
	Potassium	K	19	39.1	2	8	8	1			
	Rubidium	Rb	37	85.5	2	8	18	8	1		
	Cesium	Cs	55	132.9	2	8	18	18	8	1	
	Francium	Fr	87	223.0	2	8	18	32	18	8	1

Figure 4 • 16. Summary of some element family characteristics. Use the chart to answer the problems on pages 94–95.

PROBLEMS FOR PRACTICE

Gases such as helium, neon, and argon, which belong to the helium family, usually do not react (combine) with each other or with other elements. Scientists believe that the electron groupings in atoms of these inert gases offer an explanation for this lack of reactivity. Scientists also believe that the reactivity of other elements depends upon the ease with which their atoms gain or lose electrons and achieve electron groupings like those of the inert gases.

Work each of the following problems to see how different elements may combine to form compounds:

1. Examine the beryllium family in Figure 4 • 16. How might the electron grouping of calcium (Ca) be changed to resemble the electron grouping of argon (Ar)?
2. Examine the oxygen family in Figure 4 • 16. How might an atom of sulfur (S) gain an electron grouping like that of argon (Ar)?
3. Calcium (Ca) and sulfur (S) combine to form the compound calcium sulfide (CaS). Review the answers to Problems 1 and 2 and explain how the combination of calcium and sulfur provides each with an electron grouping like that of an inert gas.
4. What is the electrical charge of a calcium atom? Of a sulfur atom?
5. What would be the electrical charge of calcium after it lost two electrons? Of sulfur after it gained two electrons?

ANSWERS TO PROBLEMS FOR PRACTICE

1. Calcium has two electrons in its outer region. If it lost these two electrons, its (new) outer region would have eight electrons. Calcium would then have the same electron grouping as that of argon.
2. An atom of sulfur has six electrons in its outer region. If it gained two electrons, its outer region would have eight electrons. Sulfur would then have the same electron grouping as argon.
3. In this reaction, calcium loses two electrons to sulfur. Both then have an electron grouping like argon, an inert gas.

4. A calcium atom has twenty protons (positive charge) and twenty electrons (negative charge). It is electrically neutral (zero charge). Sulfur has sixteen protons and sixteen electrons and is also electrically neutral. (Check this by examining the tables in Figure 4 • 16.)
5. Calcium would have an electrical charge of +2, and sulfur would have a charge of −2.

PROBLEMS

Members of the helium family (with rare exceptions) are not able to combine chemically with other elements. Chemists believe that this lack of reactivity has something to do with the structure of their electron grouping.

1. How could a sodium (Na) atom acquire an electron grouping like that of neon (Ne)?
2. How could a chlorine (Cl) atom acquire an electron grouping like that of neon? Like that of argon?
3. If an atom of sodium and an atom of chlorine are brought together, how might both atoms achieve an electron grouping like that of an inert gas?
4. How would this change affect the electrical balance (net charge) of each atom?
5. Using symbols, write formulas for the compounds most likely to be produced from a reaction between the following pairs of elements:[1]

   a. lithium and iodine
   b. sodium and bromine
   c. potassium and chlorine
   d. rubidium and fluorine
   e. cesium and bromine

[1] By general agreement among chemists, the symbol for the element that *loses* electrons is written first in a formula for a compound. For example, the formula for a compound of lithium and bromine is LiBr.

6. What would have to happen to an atom of oxygen to give it an electron grouping like that of neon?
7. How many atoms of each of the following elements would be needed to supply the electron requirements of one oxygen atom?

   a. sodium
   b. cesium
   c. magnesium
   d. barium

8. Frequently (as in Problem 7), chemical reactions require unequal numbers of atoms from the combining elements. In written formulas for such combinations, the number of atoms included from each element appears slightly below and to the right of each element's symbol. Where only one atom is included, no number is written. For example, you probably know that the formula for water is H_2O. The number 2 slightly below and to the right of H and the absence of any number after the O indicates that a molecule of water is formed from two atoms of hydrogen and one atom of oxygen. Now look at a more complex example: the formula for an aluminum oxide molecule is Al_2O_3; this means that the combining ratio for aluminum oxide is two atoms of aluminum (Al) to three atoms of oxygen. Now write the formula for the combination of oxygen with each element listed in Problem 7.
9. The atomic number of the element hydrogen is 1, and its average atomic weight is 1.008.

   a. An atom of hydrogen has how many protons? How many neutrons? How many electrons?
   b. From its electron arrangement, to which family might hydrogen belong?
   c. What would be the formula for a combination of hydrogen and chlorine? Of lithium and hydrogen? Of calcium and hydrogen?

Groups of Elements

(pages 85–96)

One of the biggest tasks facing students of chemistry is to organize a mass of data about a great number and variety of elements and compounds. One useful method is to group elements into families whose members behave similarly in chemical reactions.

PROBLEMS

1. If sodium lost one electron it would have an electron grouping like that of neon. However, the two substances would behave differently: neon would be electrically neutral, and sodium would have a charge of $+1$. There are two opposing tendencies in chemical reactions—one toward electric neutrality (no net plus or minus charge), the other toward electron groupings resembling those of inert gases. A unique characteristic of the inert gases is a lack of chemical reactivity. All other elements have a tendency to gain or lose electrons until they acquire an electron grouping similar to that of inert gases. They do this by becoming electrically charged. The further they must depart from electric neutrality, the less reactive they tend to be. Thus the most reactive elements in the families discussed are those with one or seven electrons in the outer regions of their atoms. By the same reasoning, the least reactive elements involved in chemical reactions would be members of the carbon family.
2. Chlorine could acquire an electron grouping like that of neon by losing seven electrons. Chlorine could acquire an electron grouping like that of argon by gaining one electron. In the latter case, the chlorine atom could acquire an electron grouping similar to that of inert gases and remain relatively close to electric neutrality. Thus we expect chlorine to gain one electron rather than to lose seven electrons.
3. In this reaction sodium could donate one electron to chlorine. Both atoms would then have eight electrons in their outer region and an electron grouping like that of an inert gas.
4. The sodium atom would have a charge of $+1$ (eleven protons, ten electrons). The chlorine atom would have a charge of -1 (seventeen protons, eighteen electrons).
5. *a.* LiI (lithium iodide)
   b. NaBr (sodium bromide)
   c. KCl (potassium chloride)
   d. RbF (rubidium fluoride)

   e. CsBr (cesium bromide)

6. Oxygen would have to gain two electrons to have an electron grouping like that of neon, an inert gas (2,8). Oxygen would then have a charge of -2 when combined with other elements.
7. *a.* Two sodium atoms would be needed to supply the electrons for the oxygen atom.
   b. Two cesium atoms.
   c. One magnesium atom.
   d. One barium atom.
8. *a.* Na_2O (sodium oxide)
   b. Cs_2O (cesium oxide)
   c. MgO (magnesium oxide)
   d. BaO (barium oxide)
9. *a.* Hydrogen has one proton, no neutrons, and one electron. The atomic weight of hydrogen is slightly more than 1 because deuterium and tritium, isotopes of hydrogen, have one and two neutrons, respectively.
   b. This question has two possible answers. Since hydrogen has one electron in its outer (and only) group, it could be included in the lithium family. On the other hand, hydrogen is only one electron short of having an inert gas grouping (like helium); therefore, it could be classed as a member of the fluorine (or halogen) family. In practice, chemists classify hydrogen as a "family" by itself, because its behavior is a compromise. Sometimes hydrogen gains an electron, and at other times it seems to lose its electron.
   c. Hydrogen and chlorine form HCl. Lithium and hydrogen form LiH. Calcium and hydrogen form CaH_2.

The Work of Mendeléeff

By 1830, fifty-five elements had been discovered. Each had different chemical properties, but no one had classified the elements according to these properties.

In 1864, the English chemist John Newlands arranged the elements known to him in order of their increasing atomic weights. He found that when the elements were arranged in vertical columns of seven, the horizontal rows contained elements which often have similar properties. There were so many exceptions to this, however, that other chemists thought little of his system.

A few years later, in 1869, the Russian chemist Dmitri Ivanovich Mendeléeff published a similar table, but one that avoided most of the difficulties of Newlands's arrangement. Mendeléeff took into account the "combining power" of elements (similar to the ability to gain or lose electrons) in addition to their atomic weights. He had so much confidence in his table that he left blank spaces in it when he could not find elements to fit the arrangement. He even predicted the discovery of elements to fit the blank spaces, and he described the properties of the unknown substances. His prediction turned out to be a good one, for within the next fifteen years elements possessing the predicted properties were discovered. Gallium (atomic weight 69.7) was isolated in 1875. Germanium (atomic weight 72.6) was isolated in 1886.

In his chart (Figure 4 • 17), Mendeléeff listed the elements in vertical columns in order of increasing atomic weight. Where necessary, he started new columns so that elements with similar chemical properties would appear in the same horizontal row.

Because new discoveries are constantly being made in every field of scientific research, it is not surprising that there have been many changes in the organization of the *periodic table of elements* since the time of Mendeléeff.

PROBLEMS

1. Compare the horizontal rows of elements on Mendeléeff's chart with the charts of families of elements shown elsewhere in this section. In what ways are they different?
2. Why do you think Mendeléeff grouped elements into families differently than we do?

H=1			
	Be=9.4	Mg=24	Zn=65.2
	B=11	Al=27.4	?=68
	C=12	Si=28	?=70
	N=14	P=31	As=75
	O=16	S=32	Se=79.4
	F=19	Cl=35.5	Br=80
Li=7	Na=23	K=39	Rb=85.4
		Ca=40	Sr=87.6

Figure 4 • 17. A portion of Mendeléeff's chart of the elements. Note that he inserted question marks to indicate his belief in the existence of elements with atomic weights of 68 and 70—even though such elements were unknown in his time.

The Work of Mendeléeff

(pages 97–98)

PROBLEMS

1. Encourage students to give their own opinions about differences between Mendeléeff's method of grouping elements and the way we have grouped elements into families. There are many differences. Some are trivial (e.g., use of equal sign by Mendeléeff) while others are more significant. For example, Mendeléeff grouped zinc in the same family with beryllium and magnesium. He placed calcium and strontium in a different family than beryllium and magnesium.
2. The differences might arise from two sources. First, Mendeléeff arranged elements by atomic weight and tried to make all elements known at the time fit his pattern. Second, we have gathered more information since the time of Mendeléeff, and the order in which we arrange elements is based on each element's atomic number rather than on its atomic weight.

The Periodic Table of Elements

In science, as in any other field of study, it is desirable to organize information in ways that will make it useful. The information in Figure 4 • 16 is more convenient for study and comparison than written paragraphs containing the same information. Figure 4 • 18 goes one step further by combining the families in one table. This makes comparisons of families easier and gives us a basis for predicting formulas of compounds and reactivity of elements. The table is a modification of Mendeléeff's chart.

In the modern periodic table, elements are arranged in order of increasing atomic number and grouped according to similar chemical properties. The partial table of elements shown in Figure 4 • 18 includes only the families you have studied. Study this modified table carefully. Figure 4 • 19 is a photograph of many, but not all, of the known elements, arranged in a periodic table.

PROBLEMS

1. The element astatine (At), a member of the fluorine family, has been intentionally omitted from the periodic table.
   a. What is its atomic number?
   b. What is the electron grouping for that atomic number?
2. *a.* Compare the electron groupings of hydrogen, lithium, beryllium, boron, and carbon with that of helium.
   b. Compare the electron groupings of carbon, nitrogen, oxygen, and fluorine with the electron grouping of neon.
3. The elements in some families tend to lose electrons. Elements in others tend to gain them. Carefully consider your answers to Problem 2. Make two lists—one of families that tend to gain electrons and another of families that tend to lose electrons.
4. *a.* Which family is made up of elements with the strongest tendency to lose electrons? Why?
   b. Which family is made up of elements with the strongest tendency to gain electrons? Why?
   c. Which family of elements besides the inert gas family is made up of members with the least tendency to gain *or* lose electrons? Why?

KEY

Family Name	BORON
Electron Grouping	2 8 3
Atomic Weight	27.0
Symbol	Al
Atomic Number	13
Name	Aluminum

Figure 4 • 18.
Partial table of
the elements.

FAMILY NAMES

HYDROGEN	INERT GASES HELIUM
1 1.0 H 1 Hydrogen	2 4.0 He 2 Helium

LITHIUM	BERYLLIUM	BORON	CARBON	NITROGEN	OXYGEN	FLUORINE	HELIUM
2 1 6.9 Li 3 Lithium	2 2 9.0 Be 4 Beryllium	2 3 10.8 B 5 Boron	2 4 12.0 C 6 Carbon	2 5 14.0 N 7 Nitrogen	2 6 16.0 O 8 Oxygen	2 7 19.0 F 9 Fluorine	2 8 20.2 Ne 10 Neon
2 8 1 23.0 Na 11 Sodium	2 8 2 24.3 Mg 12 Magnesium	2 8 3 27.0 Al 13 Aluminum	2 8 4 28.1 Si 14 Silicon	2 8 5 31.0 P 15 Phosphorus	2 8 6 32.1 S 16 Sulfur	2 8 7 35.5 Cl 17 Chlorine	2 8 8 39.9 Ar 18 Argon
2 8 8 1 39.1 K 19 Potassium	2 8 8 2 40.1 Ca 20 Calcium	2 8 18 3 69.7 Ga 31 Gallium	2 8 18 4 72.6 Ge 32 Germanium	2 8 18 5 74.9 As 33 Arsenic	2 8 18 6 79.0 Se 34 Selenium	2 8 18 7 79.9 Br 35 Bromine	2 8 18 8 83.8 Kr 36 Krypton
2 8 18 8 1 85.5 Rb 37 Rubidium	2 8 18 8 2 87.6 Sr 38 Strontium	2 8 18 18 3 114.8 In 49 Indium	2 8 18 18 4 118.7 Sn 50 Tin	2 8 18 18 5 121.8 Sb 51 Antimony	2 8 18 18 6 127.6 Te 52 Tellurium	2 8 18 18 7 126.9 I 53 Iodine	2 8 18 18 8 131.3 Xe 54 Xenon
2 8 18 18 8 1 132.9 Cs 55 Cesium	2 8 18 18 8 2 137.4 Ba 56 Barium	2 8 18 32 18 3 204.4 Tl 81 Thallium	2 8 18 32 18 4 207.2 Pb 82 Lead	2 8 18 32 18 5 209.0 Bi 83 Bismuth	2 8 18 32 18 6 (209) Po 84 Polonium		2 8 18 32 18 8 (222) Rn 86 Radon

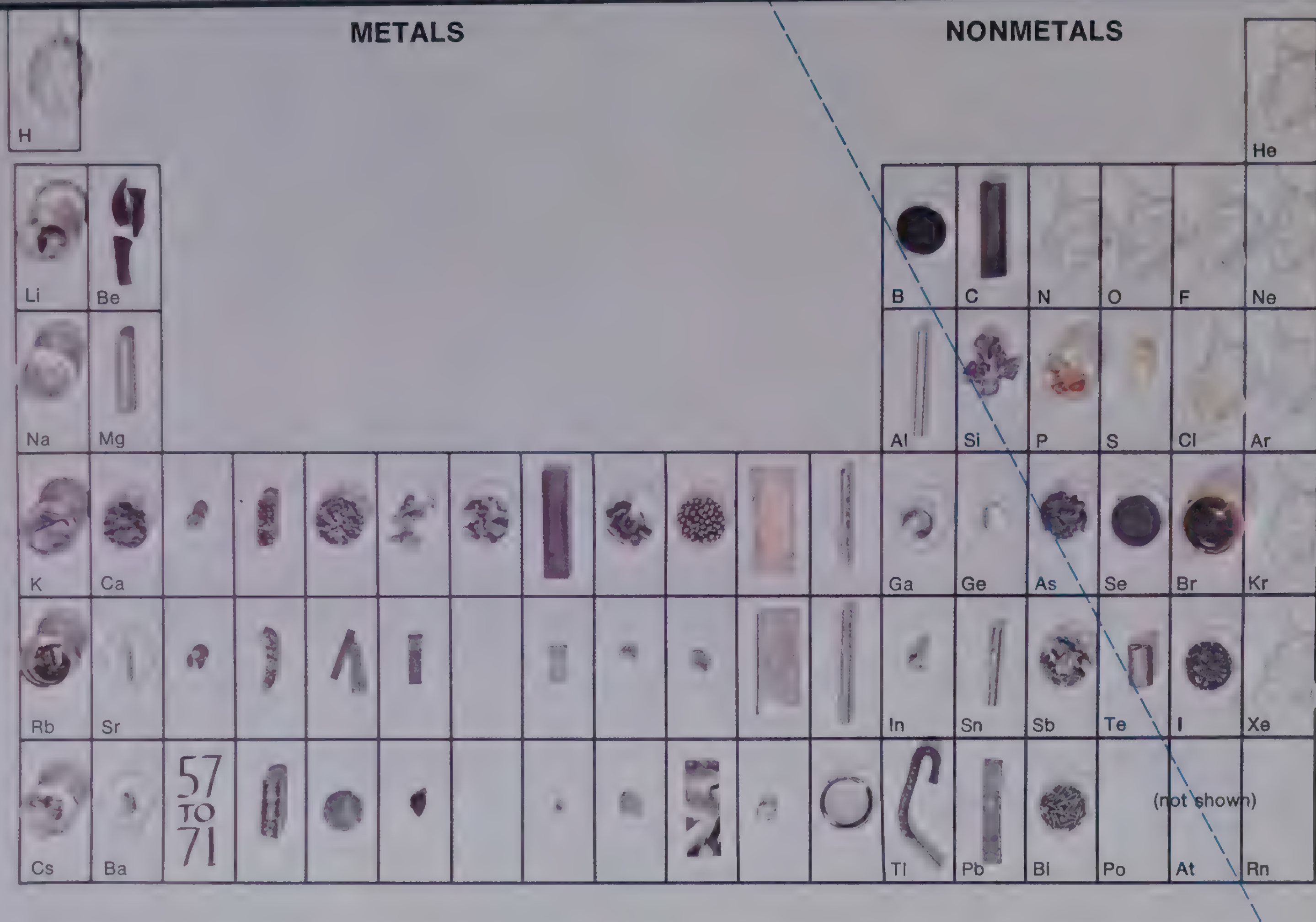


Figure 4 • 19. This photo shows samples of some 66 of the 103 known elements, arranged as in the periodic table. Suggest some reasons why all of the elements are not shown in the photo. What does this photo suggest about each family? Try to account for differences within each family.

The Periodic Table of Elements

(pages 99–101)

The modified periodic table shown on page 100 does not include elements 21 to 30, 39 to 48, 57 to 80, 85, and 89 to 103. The omissions are intentional, and the reason for them is twofold: first, no additional basic concepts could be presented by introducing twenty-four more families; second, there tends to be more variability in the behavior of members of the families omitted, and their inclusion would be more likely to confuse students than to help them.

PROBLEMS

1. *a.* The atomic number of astatine is 85, since there is a blank space between atomic numbers 84 and 86 in the periodic table.
   b. The electron grouping for astatine is 2, 8, 18, 32, 18, 7.
2. *a.* Hydrogen has one less electron than helium. Lithium has one more electron than helium. Beryllium has two more electrons than helium. Boron has three more electrons than helium. Carbon has four more electrons than helium.
   b. Carbon has four less electrons than neon. Nitrogen has three less electrons than neon. Oxygen has two less electrons than neon. Fluorine has one less electron than neon.
3. Students may prepare lists similar to the following:

Figure T-4 • 3.

Families Tending to Lose Electrons	*Families Tending to Gain Electrons*
Lithium Beryllium Boron	Nitrogen Oxygen Fluorine

4. *a.* Elements in the lithium family have the strongest tendency to lose electrons. They achieve the electron grouping of an inert gas by losing just one electron (which results in an excess charge of only +1). Elements in other families must depart further from electric neutrality to obtain an electron grouping like that of an inert gas.
   b. Elements in the fluorine family have the strongest tendency to gain electrons. They achieve the electron grouping of an inert gas by gaining just one electron (which results in an excess charge of only −1). Members of the carbon family must either

gain or lose four electrons to achieve the electron grouping of an inert gas. To achieve the electron grouping of an inert gas, members of the carbon family have to depart further from electric neutrality than do members of other families. This means that members of the carbon family have the least tendency to gain or lose electrons.

NOTE: *The concept of* covalence, *or sharing of electrons, is intentionally omitted at this point. The tendency of carbon and other elements to share electrons is discussed in a later section.*

The Mole Concept *(Optional)*

You know that atoms and molecules are very small—too small to be weighed one at a time. In fact, the most sensitive scale or balance cannot detect the difference in weight between 100,000 atoms and 500 billion atoms!

A larger, measurable, more workable unit must be established when an individual unit is too small to be conveniently detected or weighed. This unit must be made up of a certain number of the smaller units taken as a group.

Atoms and molecules are much too small to be seen or handled individually, so a larger unit—called a *mole*—is used. Atoms of hydrogen are lighter than atoms of any other kind of element. Chemists decided that 1 gram of hydrogen should be the standard. The number of atoms of hydrogen in 1 gram of hydrogen is the number of atoms in a mole. Many experiments have been carried out to find the number of atoms in a mole. The details of these experiments involve concepts, measurements, and assumptions beyond the scope of this course. The investigations indicate that the number of atoms in a mole is approximately 602,400,000,000,000,000,000,000 (usually written 6.024×10^{23}). This number is called *Avogadro's number*, honoring Italian chemist Amedeo Avogadro (1776–1856), who first suggested a method of comparing the relative molecular weights of different gases.

By determining the weight of the amount of an element that will combine with 1 gram of hydrogen, it is possible to establish how much 1 mole of that element would weigh. For simplicity we will use 6×10^{23} to represent the number of atoms in a mole. If 1 gram of hydrogen contains 6×10^{23} atoms (1 mole), then each atom of hydrogen must weigh $\frac{1}{6 \times 10^{23}}$ grams. (This is the same as saying that if 1 pound of oranges contains three oranges, then each orange must weigh ⅓ of a pound.) If 1 atom of helium weighs four times as much as an atom of hydrogen, then 6×10^{23} atoms (1 mole) of helium must weigh four times as much as 6×10^{23} atoms (1 mole) of hydrogen. In other words, 1 mole of helium must weigh 4 grams. The weight in grams of 1 mole of any

element is called the *gram atomic weight* of that element. Thus if we know that the atomic weight of an element is (say) 23, we know that 1 gram atomic weight, or 23 grams, will be the weight of 6×10^{23} atoms (1 mole) of that element.

Similarly, if we know that the molecular weight of a compound is (say) 18, we know that 1 gram molecular weight, or 18 grams, will be the weight of 6×10^{23} molecules (1 mole) of those molecules. A mole of water contains 6×10^{23} molecules of water. Each molecule of water (H_2O) contains 2 atoms of hydrogen and 1 atom of oxygen. Thus a mole of water contains 12×10^{23} atoms of hydrogen and 6×10^{23} atoms of oxygen. If 6×10^{23} atoms of hydrogen weigh 1 gram, then 12×10^{23} atoms weigh 2 grams. One mole of oxygen weighs 16 grams (1 gram atomic weight). So 1 mole of water must weigh 2 + 16, or 18, grams.

PROBLEMS

1. Use the periodic table (Figure 4 · 18) to find the number of grams in 1 mole of each of the following compounds:[2]

   a. HCl *c.* H_2SO_4 *e.* $CuSO_4$
   b. NH_3 *d.* $K_2Cr_2O_7$

2. If a pencil weighs 20 grams, how much would a mole of pencils weigh?

[2] Elements and atomic weights not listed in your periodic table are chromium (Cr), 52.0, and copper (Cu), 63.5.

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The Mole Concept *(Optional)*

(pages 102–103)

The student material states that chemists selected hydrogen as the standard for atomic weight. This definition helps students gain an understanding of the mole concept and atomic weight, although the new standard for atomic weight is an isotope of carbon. We feel it is better to focus students' attention on the concepts of atomic weight and the mole, rather than on the selection of a standard by which they are measured. The problem of measurement is further complicated because the weight of an individual atom, or even billions of atoms, cannot be measured.

The most sensitive balance will respond to differences in weight on the order of 0.00000001 grams (10^{-8}). Five hundred billion (5×10^{11}) atoms do not measurably affect such a balance!

SAMPLE CALCULATION:

Uranium: gram atomic weight = 238
Sensitivity of balance: 0.00000001 g

$$\text{weight of sample} = \frac{500 \times 10^9 \text{ atoms} \times 238 \text{ g/mole}}{6.024 \times 10^{23} \text{ atom/mole}} = 0.0000000002 \text{ g or } 2 \times 10^{-10} \text{ g}$$

The mole concept will be useful for students who will take a course in chemistry. The unit usually employed to specify the strength of solutions is *molar concentration* (M). A 1-molar (1M) solution is prepared by adding solute to solvent in the ratio of 1 mole of solute per liter of solution. After completing each investigation in Section Five, you might give interested students the directions used to prepare the solutions and ask them to calculate the concentration in moles per liter (molarity). This will provide additional work with the mole concept. Sections Six and Eleven will provide students with an opportunity to use the mole concept in optional work.

PROBLEMS

1. Emphasize that the gram atomic weight of an element is the weight, in grams, of 1 *mole* (6.024×10^{23} atoms) of that element.
2. If one pencil weighs 20 grams, a mole of pencils would weigh $20 \times 6.02 \times 10^{23}$ grams, or 120.4×10^{23} grams.

Many students may find the mole concept difficult to apply. In Section Six, "On Your Own: Moles of Water in Bluestone?" students are

Figure T-4 • 4.

Element	Atomic Weight	Grams/Mole of Compound
1. *a.* HCl:		
H	1.0	1.0
Cl	35.5	35.5
		36.5 grams
b. NH_3:		
N	14.0	14.0
H	1.0	3 × 1.0 = 3.0
		17.0 grams
c. H_2SO_4:		
H	1.0	2 × 1.0 = 2.0
S	32.1	32.1
O	16.0	4 × 16.0 = 64.0
		98.1 grams
d. $K_2Cr_2O_7$:		
K	39.1	2 × 39.1 = 78.2
Cr	52.0	2 × 52.0 = 104.0
O	16.0	7 × 16.0 = 112.0
		294.2 grams
e. $CuSO_4$:		
Cu	63.5	63.5
S	32.1	32.1
O	16.0	4 × 16.0 = 64.0
		159.6 grams

asked to determine the number of water molecules needed in the crystallization of copper sulfate. It is essential that students understand the mole concept if they are to perform the investigation. You may wish to give additional problems so students can gain some facility in using this idea.

The data provided in the following demonstration may be used to build additional problems:

Formula	*Wt. (grams/mole)*	*Formula*	*Wt. (grams/mole)*
BaO	153.4	CaS	72.2
BeO	25.0	CO_2	44.0
$BeCl_2$	80.0	GaF_3	126.7
BiI_3	589.7	NH_4ClO_3	101.5
$AsBr_3$	314.6	$GeCl_4$	214.6
$SbCl_3$	228.3	$PbAs_2O_7$	104.6
$CaCO_2$	100.1	$Mg_2P_2O_7$	222.6
Ca_3N_2	148.3	Mg_3TeS_5	361.0

Figure T-4 • 5.

DEMONSTRATION: The Concept of Relative Weight

To emphasize the concept of atomic weights as an example of relative weight, weigh a number of objects of different kinds and ask students to calculate the relative weights. The objects should have a wide range in weight. The list might include paper clips, staples, sheets of paper, nails (of uniform size), rulers, erasers, and so forth.

In selecting the number of objects of one kind to be weighed, the following factors might be discussed with the class:

1. *Precision of Measurement:* A very sensitive balance is needed to weigh ten staples to more than one significant figure. It might be necessary to weigh a hundred or even a thousand staples at a time.
2. *Capacity of the Instrument:* The more objects you can weigh at a time, the more precisely you can determine the weight of an individual object (assuming that they are uniform). On the other hand, there is an upper limit to the amount that can be weighed by a particular scale. For example, your laboratory probably does not have a balance capable of weighing a case of Ditto paper or a barrel of nails.
3. *Availability of the Sample:* While a thousand staples is relatively easy to collect, a thousand chalkboard erasers is probably more difficult to obtain.
4. *Ease of Counting:* Banks very often roll coins in paper and use the length of a roll as an indication of the number of coins in it. If a large number of coins is to be counted, such a procedure may be more precise than a coin-by-coin count, since the person counting may make an error. This procedure might be very useful for staples and paper, but would be less suitable with common nails. In a sense, this method is comparable to finding the number of moles of a gas by measuring the temperature, volume, and pressure of the

sample. Students are probably not ready to understand detailed calculations involving this last example (molar volume of a gas), but they might appreciate knowing that there are parallels between the procedures in this demonstration and the actual methods used in determining atomic weights. The problem of counting is really the most difficult one in the measurement of atomic weights. It might be unprofitable to ask even an above-average student to read more about the determination of atomic weights, but an outstanding student could learn a great deal from a study of a text such as *Foundations of Modern Physical Science,* by Gerald Holton and Duane Roller, Reading, Mass.: Addison-Wesley Publishing Co., 1958.

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FILMS

Chemical Families. CHEM Study Film, Modern Learning Aids. 22 minutes. Color.

**Helium.* Bureau of Mines Film #260. 28 minutes. Color.

**The Magic of Sulfur.* Bureau of Mines Film #255. 26 minutes. Color.

**The World of Phosphorus.* Bureau of Mines Film #257. 27 minutes. Color.

* Available on a free loan basis from the Bureau of Mines Films, 4800 Forbes Avenue, Pittsburgh, Penn. 15213.

SECTION FIVE

Investigating Properties of Chemical Families

SECTION FIVE

Investigating Properties of Chemical Families

(pages 105–132)

Preview

Once they have established a useful system of classification, scientists are often able to predict and test their ideas. Section Five emphasizes how chemists are able to predict that certain reactions *should* occur and then, by experimenting, to determine if their predictions are supported by the data.

Students apply these skills as they initiate, design, interpret, and redesign their own investigations.

In this section several elements are used to illustrate the similarity of chemical reactions that occur within a family of elements. Students should not only observe the reactions but also refine their models of matter based on their observations. Chemical reactions involve a rearrangement of electrons, and Section Five requires students to consider effects of such rearrangements on members of a chemical family.

Students are introduced to the concept of ionization reactions and to the term *ion*. An Inquiry Demonstration, on the conductivity of solutions (page 108D), is provided in the teacher's edition. After seeing this demonstration, students should realize that ions must be present in a solution if it is to conduct electricity. Students learn that compounds containing carbon are poor conductors since many carbon compounds do not produce ions. Ordinary table sugar is used as an example of a carbon compound that is a poor conductor. Note that the term *nonconductor* is avoided in favor of *poor conductor*. This is because nearly any substance will act as a conductor if enough voltage is applied.

Following the demonstration, students predict which of eight solutions should be good conductors or poor conductors. They then carry

out the investigation and record their results on charts they have prepared in their notebooks.

The nature of acids and bases is explained with the aid of diagrams. Students should understand the formation of salts and neutralization (pH 7) when equivalent amounts of an acid and a base are combined.

An investigation, "Testing for Acids and Bases," (page 114) allows students to determine whether various solutions are acids, bases, or neither by using blue and red litmus paper. "On Your Own: Acid or Base?" (page 115) provides students with an opportunity to test various household products with litmus paper to determine whether these products are acids, bases, or something else.

An optional activity (page 115C) in the teacher's edition gives students an opportunity to observe color changes in solutions of pH 1 through 7. Four different indicators are used. While listed as optional, this activity should be performed, at least as a demonstration.

An Inquiry Demonstration (page 119A) illustrates neutralization using equivalent amounts of NaOH and HCl to form NaCl, a salt. Another Inquiry Demonstration (page 119B) involving both neutralization and precipitation is suggested. This should be performed before students carry out Investigation 5.4. Students should remember the demonstration, as it is critical in understanding some of the reactions in Section Six.

A short section on balancing equations is included for those students who are likely to take a course in chemistry and for students who find this activity interesting. Students should thus begin to understand the conservation of matter.

Under the title "Compounds of Carbon," the concept of atoms "sharing" electrons is introduced. We have avoided the term *covalent bonding* as unnecessary in this course. (If students take courses in chemistry or modern high school biology, they should readily understand covalent bonding.) The material begins with structural formulas for carbon and hydrogen. Illustrated next is how carbon and hydrogen can form large numbers of compounds by sharing electrons. The difference between empirical and structural formulas is emphasized.

Some carbon compounds found in living things are discussed. Ring structures are introduced, which lead to the structure of simple and compound sugars.

PLANNING AHEAD

Check material lists for each demonstration and investigation to be sure you have the equipment and supplies on hand.

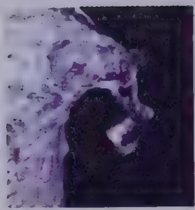
Inquiry Demonstration (page 108D).	Be sure the conductivity electrode system is working properly. Clean the probes with steel wool.
Investigation 5.1.	Several solutions must be prepared. All conductivity systems should be checked and the probes cleaned.
Investigation 5.2.	Several solutions must be prepared and household chemicals assembled.
Investigation 5.3.	Two solutions must be prepared.
Inquiry Demonstration (page 119A).	Two solutions must be prepared.
Inquiry Demonstration (page 119B).	Several solutions must be prepared.
Investigation 5.4.	Several solutions must be prepared.
Inquiry Demonstration (page 124A).	Seven solutions must be prepared.
Investigation 5.5.	Individual sample sets must be prepared.

LEARNING OBJECTIVES

Given the opportunity to inquire, to investigate, to interpret data, and to offer hypotheses about the activities in this section, most students should be able to—

- Explain ionization as a process of electron transfer;
- Recognize that the periodic chart is organized so that families of elements placed to the left of the chart tend to lose electrons and those toward the right gain electrons;
- Describe situations in which electrons are shared;
- Interpret the data gained by use of the conductivity indicator system on solutions;
- Predict whether or not a solution will contain ions by inspection of the chemical formula of its contents;
- Recognize that a precipitate may occur when certain ions are mixed;
- Explain the acidic or basic nature of substances in terms of the concentrations of hydrogen and hydroxide ions;
- Test solutions to find if they are acidic, basic, or neutral;
- Describe neutralization and salt formation for a limited number of acid-base reactions;
- Recognize that if a precipitate forms during neutralization, the mixture will have low conductivity;
- Write balanced chemical equations for simple inorganic reactions;
- Explain why most compounds containing carbon are of the shared-electron type;

- Recognize that large organic molecules result from the ability of carbon atoms to share electrons with other carbon atoms;
- Manipulate and use simple laboratory apparatus and chemical solutions (conductivity indicator, several chemicals, acid-base indicators, tongs, magnifiers, slides, organic solutions);
- Design investigations to determine the behavior of an assortment of carbon compounds;
- Prepare a concise written report on the chemical analysis of certain carbon compounds indicating experimental design, procedures, results, and interpretations.



You have seen that the periodic table is arranged in families of elements and that elements are placed within families on the basis of their atomic number and their electron grouping. All elements of a family, however, do not behave in exactly the same way. Nor do all elements of a family have exactly the same chemical and physical properties. Aluminum, a member of the boron family, is used to make cooking utensils. Yet thallium, a member of the same family, is used as an insecticide. Nitrogen is part of the air we breathe. Arsenic, a well-known poison, is in the same family. Carbon forms compounds in living things, but most lead compounds are poisonous.

It would therefore be dangerous and very difficult to test for the properties of all elements in our modified table. But we can find several elements that may be safely used to illustrate the similarity of chemical reactions within families of elements. It is important not only to observe the reactions, but also to bring our model of atoms into agreement with the observations. Chemical reactions involve a rearrangement of electrons, and we must consider the effect of this rearrangement on atoms.

Ionization Reactions

You have learned that the number of electrons in an atom is equal to the number of protons as long as the atom remains electrically neutral. If atoms gain electrons, they become negatively charged. And if they lose electrons, they become positively charged. The process in which atoms become electrically charged is called *ionization*. When an atom becomes electrically charged, it is called an *ion*.

Compare the structures of neutral atoms with their ions, as illustrated in Figures 5 • 1 and 5 • 2.

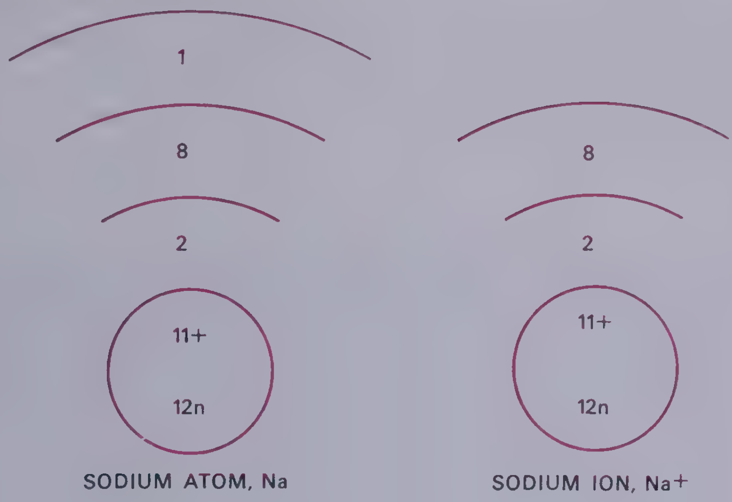


Figure 5 • 1. The sodium atom is electrically neutral because it has an equal number of electrons and protons. The sodium ion, however, has a positive charge because it has eleven protons and only ten electrons.

Figure 5 • 2. The fluorine atom is electrically neutral because it has an equal number of electrons and protons. The fluorine ion has a negative charge because it has ten electrons and only nine protons.

The sodium and fluorine ions shown have achieved an electron grouping like that of neon—sodium by losing an electron, and fluorine by gaining an electron. All members of a family tend to form ions having the same charge, as shown in Figure 5 • 3.

Figure 5 • 3. Ions formed by three families.

Lithium Family	*Beryllium Family*	*Fluorine Family*
Lithium loses one electron to form Li^{+1}	Beryllium loses two electrons to form Be^{+2}	Fluorine gains one electron to form F^{-1}
Sodium loses one electron to form Na^{+1}	Magnesium loses two electrons to form Mg^{+2}	Chlorine gains one electron to form Cl^{-1}
Potassium loses one electron to form K^{+1}	Calcium loses two electrons to form Ca^{+2}	Bromine gains one electron to form Br^{-1}
Rubidium loses one electron to form Rb^{+1}	Strontium loses two electrons to form Sr^{+2}	Iodine gains one electron to form I^{-1}
Cesium loses one electron to form Cs^{+1}	Barium loses two electrons to form Ba^{+2}	
	Radium loses two electrons to form Ra^{+2}	

FOR CLASS DISCUSSION

Which inert gas electron grouping is achieved when each of the following ions is formed?

1. beryllium Be^{+2}
2. calcium Ca^{+2}
3. chlorine Cl^{-1}
4. bromine Br^{-1}

Ionization Reactions

(pages 106–108)

Later in this section the sharing of electrons in carbon compounds will be discussed. We suggest that you postpone a discussion of covalent bonding until that time. The most important message here is to explain that two or more atoms that share electrons may form a substance that behaves like a single atom or ion. Those ions containing more than one atom are often called radicals.

FOR CLASS DISCUSSION

1. Beryllium achieves an electron grouping like helium.
2. Calcium achieves an electron grouping like argon.
3. Chlorine achieves an electron grouping like argon.
4. Bromine achieves an electron grouping like krypton.

INQUIRY DEMONSTRATION: Conductivity of Solutions

(Teacher Only)

This demonstration should familiarize students with the functioning of the conductivity indicator system (consisting of probes and a milliammeter) which students will use in Investigation 5.1 to test some solutions. It will also show them that, in the solid state, substances used to make solutions for Investigation 5.1 do not conduct electricity. You may also carry out this demonstration and the investigation that follows with a safe, battery-powered conductivity indicator.

MATERIALS

Beakers (150 ml) or small jars, 5
Sodium chloride ($NaCl$), 10 g
Sodium hydroxide ($NaOH$), 10 g
Table sugar ($C_{12}H_{22}O_{11}$), 10 g
Potassium bromide (KBr), 10 g
Barium chloride ($BaCl_2$), 10 g
Conductivity indicator system
Bare copper wire, 6 inches
Plastic ruler (6- or 12-inch) or other nonconductor

CAUTION: *NaOH is caustic.*

PROCEDURES

CAUTION: *We urge you not to use a conductivity indicator that operates on 110 volts. If you must, however, be sure that during the following procedures you do not touch both probes simultaneously with your hands or any part of your body. In Procedure B, hold the insulated handle of a screwdriver (or other insulator with metal attached) and touch the probes with the metal part. You should also avoid contact with water pipes, gas pipes, or other metal objects likely to ground you. If you use a conductivity indicator that operates on 12 volts or less, you need not observe these precautions. Service the batteries and clean the probes with steel wool annually. A conductivity indicator system consisting of conductivity probes and a milliammeter is available from the publisher.*

A. Before the class begins, place the dry chemicals in the jars. Attach labels so that students can record the name of each chemical.
B. Touch both probes of the conductivity indicator simultaneously with the copper wire to demonstrate how the indicator functions. Point out that the needle moves only when the probes are touched with a material that conducts electricity.
C. Touch both probes of the conductivity indicator simultaneously with a plastic ruler or other poor conductor.
D. Ask students to make a generalization about the results of Procedures B and C. A possible response is as follows:

   If both probes are touched simultaneously by a conductor of electricity, the needle moves. If it does not move, the substance touching both probes simultaneously is not a good conductor.
E. Touch each of the dry chemicals with both probes of the conductivity indicator. Ask students to record the results. They will use this information for Investigation 5.1, in which the behavior of dry chemicals is compared with the behavior of the same chemicals in solution. None of the dry chemicals should cause an indicator reading.

NOTE: *Sodium hydroxide absorbs moisture easily. If this happens, there may be enough NaOH solution formed to short the indicator circuit. If the light glows, have students examine the contents and record their observations. Their observations should be discussed following the completion of Investigation 5.1.*

Sharing Electrons

Not all chemical reactions involve a complete transfer of electrons from one element to another. Atoms that tend to gain electrons may join together by *sharing* electrons. For example, the pure element fluorine forms molecules that contain two atoms of fluorine (F_2). Both atoms in the molecule tend to gain electrons, and so they must share some electrons between them. Other elements that form two-atom molecules in the pure state are chlorine (Cl_2), bromine (Br_2), iodine (I_2), oxygen (O_2), nitrogen (N_2), and hydrogen (H_2). In each case, molecules are made of two atoms of the same element sharing electrons equally.

When two different elements combine, the electrons will no longer be shared equally. A very common example of a compound formed by sharing electrons is water (H_2O). In carbon monoxide (CO) and carbon dioxide (CO_2), electrons are shared between carbon and oxygen atoms. There are millions of compounds formed by atoms sharing electrons.

It is also possible to have a compound in which some electrons are ionically transferred and other electrons are shared. Calcium sulfate ($CaSO_4$) is an example of that type of compound. The calcium is a positive ion (Ca^{+2}), and the sulfate is a negative ion (SO_4^{-2}). Notice that the sulfate ion contains both sulfur and oxygen atoms held together by sharing electrons, because both sulfur and oxygen tend to gain electrons. Some other examples of ions with shared electrons are nitrate (NO_3^-), hydroxide (OH^-), and carbonate (CO_3^{-2}). When a compound such as sodium nitrate ($NaNO_3$) dissolves in water, the positive sodium ions (Na^+) and the negative nitrate ions (NO_3^-) are free to move separately. But the one nitrogen and three oxygen atoms in the nitrate ion move together because they share electrons with one another.

INVESTIGATION 5.1: Conductivity of Solutions

You have observed the behavior of some solutions which contain ions. This investigation provides a direct test to find out if positive and negative ions in solution are free to move around.

MATERIALS (per team)

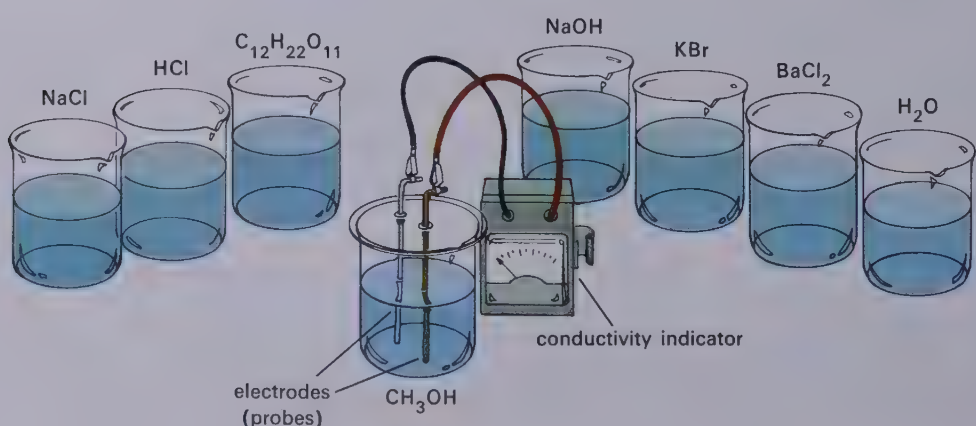
8 jars or beakers, 250 ml
Conductivity indicator system
Solutions:
- Sodium chloride ($NaCl$)
- Hydrochloric acid (HCl)
- Sodium hydroxide ($NaOH$)
- Methyl alcohol (CH_3OH)
- Table sugar ($C_{12}H_{22}O_{11}$)
- Potassium bromide (KBr)
- Barium chloride ($BaCl_2$)
- Distilled water (H_2O)

PROCEDURES

A. Arrange a series of eight jars or beakers (Figure 5 • 4), each containing one of the solutions listed. Label each jar. Copy the chart shown in Figure 5 • 5.

B. Place the two electrodes of the conductivity indicator in one of the solutions (Figure 5 • 4). Record your observations on

Figure 5 • 4. Predict what will happen to the needle on the conductivity indicator when the electrodes are placed in each solution.



the chart. Wipe the electrodes carefully and test another solution. Record your observations. Repeat with each solution. For each test, make sure that the probes remain the same distance apart and at the same depth in the solution. A piece of cardboard with two holes through which the probes are inserted will insure that the position of the probes for each test will be the same.

Figure 5 • 5.

Solution		*Reading on Conductivity Indicator*
Sodium chloride	$NaCl$	
Hydrochloric acid	HCl	
Sodium hydroxide	$NaOH$	
Methyl alcohol	CH_3OH	
Table sugar	$C_{12}H_{22}O_{11}$	
Potassium bromide	KBr	
Barium chloride	$BaCl_2$	
Water (distilled)	H_2O	

INTERPRETATIONS

1. Which elements listed seem to form compounds that conduct electricity?
2. Recall that elements in the lithium family lose electrons, and elements in the fluorine family gain electrons, more easily than do elements in other families. Do elements that gain or lose more than one electron form ions as easily as the lithium and fluorine families?
3. Name some other compounds that should conduct electricity. Be sure to check with your teacher before you begin to test any compound.
4. Compare the conductivity of the dry chemicals with the conductivity of the same chemicals in solution. Explain any differences noted.
5. Describe a model that might explain why certain solutions are able to conduct electricity while others are not.

INVESTIGATION 5.1: Conductivity of Solutions

(pages 109–111)

This investigation furnishes evidence for the existence of ions in solutions. It is essential that students understand the general functioning of the conductivity apparatus. The conductivity indicator will only give a reading when an electric charge is transferred from one probe to another. Students should realize that when the probes are dipped into a solution and the needle moves, electric charges in the solution are being transferred from one probe to the other. This is evidence for the existence of ions in the solution.

MATERIALS

Prepare the following stock solutions before beginning the investigation, observing the appropriate precautions:

NaCl solution: add 6.0 g NaCl to 1 liter of water.

HCl solution: add 20 ml of concentrated hydrochloric acid to 1 liter of water.

CAUTION: *Concentrated HCl is caustic. Add the acid to the water slowly. If it is added too rapidly, or if water is added to the acid, the heat produced may cause the acid to spatter dangerously.*

NaOH solution: add 4.0 g of sodium hydroxide to 1 liter of water.

CAUTION: *NaOH is caustic.*

Methyl alcohol solution: add 20 ml methyl alcohol to 1 liter of water.

Sugar solution: add 34.2 g of sugar to 1 liter of water.

KBr solution: add 12 g of potassium bromide to 1 liter of water.

$BaCl_2$ solution: add 19.8 g of barium chloride to 1 liter of water.

PROCEDURES

A. Baby-food jars work well as containers.

B. Results should be as shown in Figure T-5 • 1.

Deviations from these results can probably be attributed to failure to clean the electrodes between trials or to impurities in the water used. A conductivity indicator with a very sensitive milliammeter shows that water does conduct small amounts of electricity.

Solution		Reading on Conductivity Indicator
Sodium chloride	$NaCl$	Yes
Hydrochloric acid	HCl	Yes
Sodium hydroxide	$NaOH$	Yes
Methyl alcohol	CH_3OH	No
Table sugar	$C_{12}H_{22}O_{11}$	No
Potassium bromide	KBr	Yes
Barium chloride	$BaCl_2$	Yes
Water (distilled)	H_2O	No

Figure T-5 • 1. Sample data for Procedure B. Readings will not be the same for all solutions and will not necessarily be constant for any particular solution.

TERPRETATIONS

Sodium, potassium, and barium combined with chlorine or bromine seem to form compounds that conduct electricity. Depending on the elements with which they are combined, hydrogen and oxygen may form compounds that conduct electricity. Compounds that contain carbon do not seem to conduct electricity.

Elements that gain or lose electrons easily form compounds that ionize easily. Elements with more electrons to gain or lose form compounds that are less likely to ionize.

Any combination of a lithium family element and a fluorine family element should produce ions in solution. In combination, members of the beryllium and oxygen families usually produce compounds that conduct when in solution. Compounds containing members of the carbon family usually form solutions that do not conduct. Before the students carry out any tests, be sure that none of the compounds they suggest release toxic vapors or present other hazards.

If a current is to flow, charged particles must be free to move. In some dry chemicals, such as sodium chloride, charged particles are present but are not free to move. If sodium chloride is dissolved in water or melted, it conducts electricity. While it might be useful to demonstrate the melting of NaCl, the high temperatures needed and the corrosive action of the chemicals produced at the electrodes make it unsafe. If you wish to demonstrate this effect and are willing to replace the damaged probes, use silver chloride—it melts at a much lower temperature. Place the sample in a crucible and heat until it becomes molten. Insert the probes. There should

be a reading. Allow the sample to cool. As it solidifies, the reading should gradually lessen.

5. Elements with electron groupings most closely resembling those of the inert gases form compounds that conduct electricity in solution. When uncharged atoms lose or gain electrons, they become ions. If these ions are free to move about in the solution, the solution conducts electricity.

Students are likely to suggest that, except for the inert gas family, elements of families that are widely separated on the periodic table form compounds that produce ions; those that belong to families near the center of the table do not. This model must necessarily be simple, since background information sufficient for a more comprehensive model has yet to be developed. A discussion of these interpretations should lead to an understanding of (1) the bonding in ionic and covalent solids, (2) the changes that take place when a material goes into solution, and (3) the reason that some materials are more soluble than others. At this point attempt to elicit ideas from the students rather than to present "answers," even if all students do not give completely satisfactory responses. The role of water in causing materials to dissolve and in the conductivity of certain solutions is developed in future investigations. Pure water and solutions of such materials as sugar and alcohol lack conductivity. This suggests that in some substances electrons are not transferred from one atom to another.

FOR FURTHER INVESTIGATION

If you would like to challenge the students, ask them to predict the conductivity of a solution of sodium carbonate (Na_2CO_3), which contains carbon. They might suggest this compound does not form ions. Actually it conducts well because both the sodium ions and the carbonate ions (CO_3^{-2}) are free to move.

Acids and Bases

The structure of water is a key to understanding the behavior of materials we call *acids, bases,* and *salts.* Most water particles are molecules. Only a small minority are ions. Consider the following equation:

$$HOH \rightleftharpoons H^+ + OH^-$$

The heavy arrow pointing to the left indicates that most water particles exist as molecules (HOH or H_2O) while only a few hydrogen ions (H^+) and hydroxide ions (OH^-) are present. Thus water is said to be weakly ionized. Note that the oxygen atom and one of the hydrogen atoms have such a strong attraction for each other that the two are written together—they form one ion. There are so few ions in pure water that only very sensitive equipment can detect them. The attraction between H^+ and OH^- ions is strong. These two ions combine more easily than they separate.

What happens when we put some sodium hydroxide ($NaOH$) into a beaker of water? Sodium hydroxide is made up of ions—even in the solid state. When placed in water, these ions become free to move about. We can write this as an equation, as we did for the ionization of water, above. But since all of the sodium hydroxide separates into ions, we use only one arrow, pointing to the right.

$$NaOH \longrightarrow Na^+ + OH^-$$

When both water and sodium hydroxide are in the same solution, we can write:

$$HOH \rightleftharpoons H^+ + OH^-$$

$$NaOH \longrightarrow Na^+ + OH^-$$

The hydrogen ion from the water is likely to combine with a hydroxide ion either from the water or from the sodium hydroxide. As a result, a water molecule is formed. Adding the sodium hydroxide to the water greatly increases the concentration of hydroxide ions. A substance that produces an excess of hydroxide ions (OH^-) in water is called a *base.*

If we add hydrochloric acid to the water instead of sodium hydroxide, the effect is quite different. Hydrochloric acid ionizes almost completely; we indicate this by a heavy arrow to the right.

$$HCl \rightleftharpoons H^+ + Cl^-$$

When the ionization reactions for both HCl and H_2O are considered at the same time, we write:

$$HOH \rightleftharpoons H^+ + OH^-$$

$$HCl \rightleftharpoons H^+ + Cl^-$$

The hydroxide ion from water is likely to combine with a hydrogen ion either from the water or from the hydrochloric acid. And again a water molecule is formed. Adding hydrochloric acid to water decreases the already small concentration of hydroxide ions and produces a large concentration of hydrogen ions. A substance that produces an excess of hydrogen ions (H^+) in water is called an *acid*.

The greater the concentration of free H^+ ions produced, the stronger the acid. Strong acids and bases are highly *corrosive*. They can cause painful burns and damage to clothing.

Since the properties of an acid depend upon the presence of H^+ ions, we can expect to find hydrogen in all acids. On the other hand, hydrogen also is part of the OH^- ion, which we find in bases. The difference between molecules of acids and those of bases depends upon the way hydrogen is attached to the rest of the molecule. In acids, a hydrogen atom separates from the rest

of the molecule. In bases, the hydrogen is so strongly attached to an oxygen atom that the two stay together when the molecule breaks apart to form ions.

Note that hydrogen is a family by itself in the periodic table. Its behavior is a little different from that of any other element. Hydrogen is the lightest known gas. If enough pressure is applied to a quantity of hydrogen gas at a very low temperature, it becomes a liquid and can be used as rocket fuel. Yet when equal amounts of H^+ and OH^- ions are present, the product is water.

INVESTIGATION 5.2: Testing for Acids and Bases

How can you tell if a substance is an acid or a base? If you use chemical indicators to answer this question, you have to know how its appearance differs in acids and bases.

MATERIALS (per team)

- 4 small jars or beakers
- Dilute solution of NaOH
- Dilute solution of HCl
- Salt water
- Litmus paper (red and blue)
- Bromothymol blue indicator, 1 dropper bottle
- Several household substances

PROCEDURES

A. Label four beakers or jars as follows: *NaOH, HCl, Salt water, Tap water.* Pour approximately 10 ml of each liquid into the proper beaker.

B. Copy the chart shown in Figure 5 • 6 in your notebook. Dip both red and blue litmus paper into each liquid and record your observations on the chart. Then add three drops of bromothymol blue indicator solution to each beaker and record your observations on the chart.

	NaOH	*HCl*	*Salt Water*	*Tap Water*
Red litmus				
Blue litmus				
Bromothymol blue				

Figure 5 • 6.

The results of this test should be kept in your notebook for future reference.

INTERPRETATIONS

From your data determine the answer to each of these questions:

1. What would happen if red litmus paper was placed in a substance with an excess of OH^- ions? An excess of H^+ ions?
2. What would happen if blue litmus paper was placed in a solution with an excess of OH^- ions? H^+ ions?
3. Which paper would be blue in a base?
4. Which would be red in an acid?
5. What happens when the bromothymol blue indicator is placed in a basic solution? In an acid solution? In a neutral solution?

PROCEDURES

C. Obtain one of the unknown household substances and test to find if it is acidic, neutral, or basic.

D. Test the household substances to find if they are acidic, neutral, or basic. Record the result of each test in your notebook.

ON YOUR OWN: Acid or Base?

Obtain a supply of both blue and red litmus paper. Test various household chemicals while at home. Determine which are acids or bases. You might try baking soda, vinegar, detergents, and so forth. If labels are present on the box or bottle containing the material you wish to test, try to determine *why* a particular substance is an acid, a base, or neither.

INVESTIGATION 5.2: Testing for Acids and Bases

(pages 114–115)

Students should learn how to identify substances that are acidic, neutral, and basic. This test is useful in the analysis of substances and should be helpful in understanding the process of neutralization.

MATERIALS

Prepare the following solutions before beginning the investigation:

NaOH solution: add 4.0 g dry sodium hydroxide to 1000 ml of water.

CAUTION: *Solid sodium hydroxide is highly caustic and should not touch the skin. The solution is relatively dilute but could be very harmful if it is splashed into the eye. Warn students of the danger with both sodium hydroxide and hydrochloric acid solutions. If either an acid or a base is splashed into the eye, wash thoroughly with water for several minutes and call a physician immediately.*

HCl solution: add 10 ml of concentrated hydrochloric acid to 1000 ml of water.

CAUTION: *Concentrated hydrochloric acid is highly caustic and must be handled with great care. Avoid breathing the acid fumes.*

NaCl (salt) solution: add 6.0 g sodium chloride to 1000 ml of water.

The amounts prepared should be sufficient for 100 students, assuming careful measuring of the volumes and no spillage. However, since the materials are not expensive and some difficulty might be experienced in measuring the smaller amounts of the reagents, it is suggested that 1000 ml of solution be prepared, even if you have only one class to supply. Reserve some of each solution to issue as unknowns in Procedure C.

Bromothymol blue is an acid-base indicator and may be purchased ready to use in solution, or (more economically) as a powder. To prepare a solution from the powder, boil distilled water (to expel CO_2) and let it cool. Add 0.1 gram of bromothymol blue to 100 ml of water. It can be stored for extended periods of time and is conveniently dispensed from a dropper bottle.

CAUTION: *Bromothymol blue will stain clothing.*

An assortment of household chemicals could be selected from the following: baking powder, fruit and fruit juice, Alka Seltzer, aspirin, disinfectants, soaps, detergents, bleaches, and cleansers. These should be assembled and labeled; often, different brands have greatly different properties.

You may want to ask students to bring some items from home.

PROCEDURES

A. No comment.

B. The chart should resemble that in Figure T-5 • 2.

	NaOH	*HCl*	*Salt Water*	*Tap Water*
Red litmus	Blue	Red	Red	*
Blue litmus	Blue	Red	Blue	*
Bromothymol blue	Blue	Yellow	Green	*

* The pH of tap water varies from place to place. It may be basic, neutral, or acidic.

Figure T-5 • 2.

INTERPRETATIONS

1. Red litmus would be blue in OH^- excess and red in H^+ excess.
2. Blue litmus would be blue in OH^- excess and red in H^+ excess.
3. Both papers would be blue in a base.
4. Both papers would be red in an acid.
5. Bromothymol blue is blue in a base, yellow in an acid, and green in a neutral solution.

PROCEDURES

C. You might give students samples from unknown bottles to test at their own lab station or set up a special station and have them perform the tests in your presence.

D. Rather than providing a set of household chemicals for each lab station, you may find it convenient to set an area aside for these chemicals and have students perform the tests there. The results will depend on the substances you select, and you should prepare a key for the substances.

Litmus paper is one of the many indicators used to determine whether a liquid is acidic, basic, or neutral. Blue litmus will turn pink if the liquid is acidic. Pink litmus will turn blue if the liquid is basic. There will be no change in the color of litmus paper if the liquid is neutral. If available, use Hydrion pH paper. It gives a better indication of how basic or acidic a solution is.

ON YOUR OWN: Acid or Base?

(page 115)

We cannot predict what substances students may test. They should be encouraged to test as many different substances as possible. Sometimes a label may indicate the presence of an H^+ ion or an OH^- ion. Or, the label may not indicate the presence of either ion (a solution of sugar, for example). You may wish to have students report their findings to the class.

OPTIONAL ACTIVITY: Acid Indicators and Hydrogen Ion Concentrations

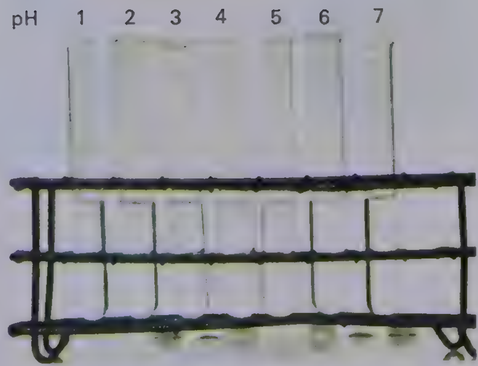
Litmus indicates only whether a solution is acidic, basic, or neutral. By using additional indicators, it is possible to determine the pH (hydrogen ion concentration) of a solution.

Have students bring in solutions from home, or provide preprepared solutions. Ask the student to add a few drops of indicator to a test tube containing the solution and compare the resulting color with the colors shown for that indicator in Figure T-5 • 3. If a large number of students are doing this activity, you might find it more convenient to prepare your own set of standard test tubes. Instructions for preparing solutions of approximate pH follow:

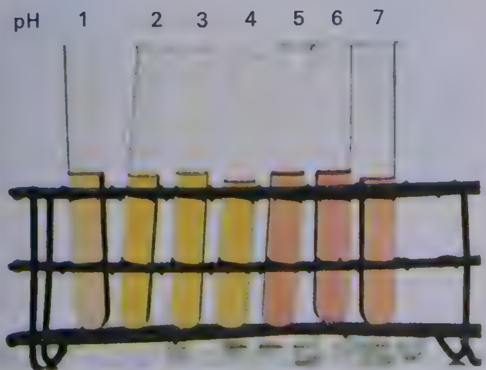
1. For a pH of 1, add 8.3 ml of concentrated hydrochloric acid to 992 ml of distilled water.
2. For a pH of 2, add 10 ml of pH 1 solution to 90 ml of distilled water.
3. For a pH of 3, add 10 ml of pH 2 solution to 90 ml of distilled water.
4. For a pH of 4, add 10 ml of pH 3 solution to 90 ml of distilled water.
5. For a pH of 5, add 10 ml of pH 4 solution to 90 ml of distilled water.
6. For a pH of 6, add 10 ml of pH 5 solution to 90 ml of distilled water.
7. For a pH of 7, use only distilled water.

Figure T-5 • 3. Acid indicators and the hydrogen ion concentration. Each set of tubes contains solutions ranging from a pH of 1 to ■ pH of 7. The color present in each tube indicates the color of a solution with that particular hydrogen ion concentration and indicator.

A. Ingredients listed on page 115C.
B. Phenyl red added to solutions in A.
C. Orange IV added to solutions in A.
D. Methyl orange added to solutions in A.
E. Bromothymol blue added to solutions in A.



A



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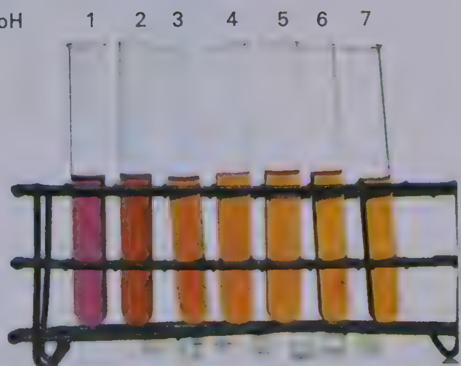
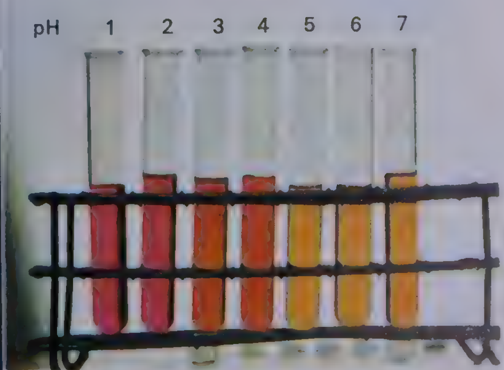
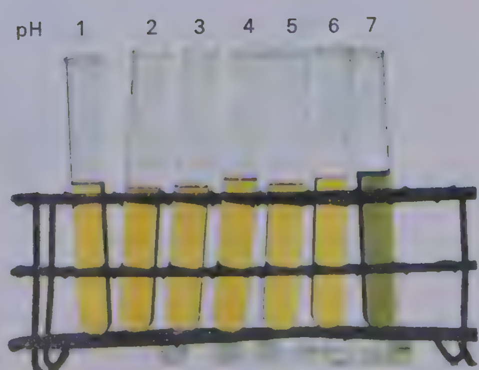


C



D



E

INVESTIGATION 5.3: Mixing an Acid and a Base

You have some evidence that acids and bases contain ions and that these ions behave differently. What do you think will happen when an acid and a base are mixed in a solution? This investigation may help you to answer that question.

MATERIALS (per team)

Beakers, 150 ml, 2
Medicine droppers, 2
Microscope slides, 3
Test tube
Wire gauze
Burner
Matches
Hydrochloric acid solution, 20 ml
Ammonium hydroxide solution, 20 ml
Bromothymol blue solution or red and blue litmus paper
Masking tape labels

CAUTION: *Be careful not to spill the chemicals. They could injure you or damage your clothing.*

PROCEDURES

A. Label one beaker *hydrochloric acid* and carefully pour the hydrochloric acid solution into the beaker. Place a medicine dropper in the solution and make sure that the rubber bulb does not touch the liquid.
B. Label the other beaker *ammonium hydroxide* and carefully pour ammonium hydroxide solution into the beaker. Place a medicine dropper in the solution, making sure the rubber bulb does not touch the liquid.
C. Light the burner and adjust it for a small flame. Put a drop of hydrochloric acid solution near the end of a microscope slide and gently warm it until the liquid just boils away. Place the

slide on the wire gauze. (CAUTION: *Remember that glass stays hot for several minutes.*) Observe the slide and record the results.

D. Put a drop of ammonium hydroxide solution near the end of another glass slide and gently warm it until the liquid just boils away. Put the slide on the wire gauze, being careful not to burn your hand on the hot glass. Observe the slide and record the results.

E. Put a drop of ammonium hydroxide solution near the end of another glass slide. Hold the dropper of hydrochloric acid solution above the drop of ammonium hydroxide and squeeze out one drop.

INTERPRETATIONS

1. Do you observe any evidence of a reaction between the two solutions? If so, describe your observations.

PROCEDURES

F. Gently warm the mixture until the liquid just boils away. Set the glass slide on the wire gauze. Turn off the burner. Observe and record the appearance of the glass slide.

INTERPRETATIONS

2. Do you observe any evidence of a reaction between the two solutions?

PROCEDURES

G. Put ten drops of ammonium hydroxide solution in a test tube. Add two drops of bromothymol blue. Add hydrochloric acid solution one drop at a time until you observe a lasting change in the color of the solution.

INTERPRETATIONS

3. What evidence does the bromothymol blue give that a reaction took place between an acid and a base?

INVESTIGATION 5.3: Mixing an Acid and a Base

(pages 116–117)

Students should gain evidence that an acid and a base can react to form a salt. The reading selection which follows the procedures should also help them to realize that the reaction also produces water.

MATERIALS

Hydrochloric acid solution: add 10 ml of concentrated acid to 1000 ml of water.

CAUTION: *Concentrated HCl is caustic and must be handled with care. Avoid breathing its fumes.*

Ammonium hydroxide solution: add 10 ml of concentrated ammonium hydroxide to 1000 ml of water.

CAUTION: *Concentrated ammonium hydroxide is caustic and must be handled with care. Avoid breathing its fumes.*

Test the solutions to see that they are about the same strength, by adding ten drops of NH_4OH to a test tube containing bromothymol blue. Then add HCl solution a drop at a time. If fewer than nine or ten drops of acid cause a color change that lasts, make the NH_4OH solution more concentrated. If more than ten or eleven drops of acid are required, make the acid solution more concentrated.

PROCEDURES

A.–B. No comment
C. The acid should leave no residue on the slide.
D. The base should leave no residue on the slide.
E. No comment

INTERPRETATIONS

1. Observing the two solutions gives no evidence of a reaction.

PROCEDURES

F. There will be a white residue on the slide.

INTERPRETATIONS

2. The white substance was not contained in either the acid or the base, so it must be a new substance produced by the reaction.

PROCEDURES

G. It should take about ten drops of the acid to change the color from blue to yellow (or green). Alternately adding one or two drops of base and acid should change the color back and forth from yellow to blue. It is difficult to get drops exactly equal in size, so students are unlikely to produce a green solution.

INTERPRETATIONS

3. The change in color indicates that the acid neutralized the base that was present.

The Formation of Salt: Neutralization

When an acid and a base are placed together in solution, a reaction occurs in which water and a salt are formed. If the acid is HCl and the base is NaOH, we can represent what happens with the following equations:

$$HCl \longrightarrow H^+ + Cl^-$$

$$NaOH \longrightarrow Na^+ + OH^-$$

Or the reaction can be shown with a simpler equation:

$$\underset{\text{(hydrochloric acid)}}{H^+ + Cl^-} + \underset{\text{(sodium hydroxide)}}{Na^+ + OH^-} \longrightarrow \underset{\text{(water)}}{HOH} + \underset{\text{(sodium chloride)}}{Na^+ + Cl^-}$$

Whenever an acid and a base combine to form water and a salt, the reaction is called a *neutralization reaction*. If the proper amount of acid is added to any base, almost all of the H^+ ions in the acid will combine with almost all of the OH^- ions in the base. The concentration of the remaining unattached H^+ and OH^- ions will be the same as in pure water. A solution that shows no surplus of H^+ or OH^- ions is called *neutral*. That is why the reaction of a base with an acid is called *neutralization*.

Notice that acids furnish not only H^+ ions but also some negatively charged ions to the solution. In the example above, HCl provides Cl^- ions. On the other hand, bases furnish not only OH^- ions but also some positively charged ions. In the example above, NaOH provides Na^+ ions. As long as water is present, these Na^+ and Cl^- ions remain free. But if the water evaporates, the ions will be attracted to each other (they have opposite charges) and form crystals of salt.

There are many kinds of acids and bases. Thus there are many different kinds of salts. In everyday conversation, when we talk

about salt we are usually referring to sodium chloride—table salt. Yet sodium cyanide, a deadly poison, is also a salt. It is formed from sodium hydroxide and hydrocyanic acid. A few salts and their chemical formulas are—

sodium chloride ($NaCl$)

sodium cyanide ($NaCN$)

potassium iodide (KI)

lithium fluoride (LiF)

Sodium and chlorine are poisonous substances. Yet table salt is an essential part of the diet of man and of many other animals. Obviously, sodium chloride must be different in some way from a simple mixture of sodium atoms and chlorine atoms. Salts are compounds. And in sodium chloride, sodium and chloride *ions* combine because of their opposite electric charges.

Neutralization and many other chemical reactions might be viewed as the mischievous actions of demons. Or they might be explained with a different model. A satisfactory model must account for changes in properties resulting from chemical reactions.

INQUIRY DEMONSTRATION: Neutralization

(Teacher Only)

If you wish to demonstrate that heat is produced during salt formation, combine equal amounts of NaOH and HCl. We do not recommend that students be allowed to perform the following demonstration because of certain hazards involved. When a concentrated base and a concentrated acid are mixed, considerable heat may be evolved. If they are combined too rapidly, a violent splattering may occur.

MATERIALS

pH (Hydrion) paper sensitive to 1 pH unit (litmus paper may be substituted)
HCl solution, 1 molar (8.3 ml of concentrated HCl added to 100 ml of water)
NaOH solution, 1 molar (4 g of solid NaOH added to 100 ml of water)
Pyrex beaker or test tube

SUGGESTED PROCEDURES

A. Test each solution with pH paper before mixing. Have students record the results in their notebooks.
B. Slowly pour 10 ml of the acid solution into 10 ml of the base solution. Have several students feel the container before and after the acid and base are combined. Ask them to attest to the heat produced. This observation should also be recorded.
C. After combining the acid and base, test the solution with pH paper. Have students record the result in their notebooks.
D. Evaporate to dryness overnight. Unless the humidity is quite high, salt crystals should be visible by morning.

This demonstration helps illustrate neutralization. As an aid, have the equation for the chemical reaction ($NaOH + HCl \longrightarrow NaCl + H_2O$) written on the blackboard for discussion.

POSSIBLE INTERPRETATIONS (for students to consider)

1. How can you account for the heat being given off? (Students should suggest that energy is involved in the reaction.)
2. From your study of acids, bases, and salts, explain how a neutralization reaction occurs. Stated another way: Why do HCl and NaOH change after being combined? (The strong attraction between H^+ and OH^- ions causes them to form water.)

NOTE: *You should perform the following demonstration before students carry out Investigation 5.4:*

INQUIRY DEMONSTRATION: Neutralization and Precipitation

(Teacher Only)

Students will observe both neutralization and precipitation as a result of the reaction between an acid and a base. An insoluble salt is formed in the reaction. This demonstration should provide background information that will help students understand precipitation reactions.

MATERIALS

Barium hydroxide, 0.018 molar—3.1 g $Ba(OH)_2$ in 1 liter of water (mix this solution thoroughly by shaking in a stoppered container)
Beakers (50 ml) or small jars, 2
Phenolphthalein solution in a dropper bottle, 10 ml (dissolve 1 g phenolphthalein in 50 ml of ethyl alcohol and add 50 ml of water)
pH (Hydrion) paper or litmus paper
Sulfuric acid, 0.018 molar—1 ml of concentrated 18-molar H_2SO_4 in 1 liter of water
Conductivity indicator system
Medicine droppers, 2

PROCEDURES

A. Pour 15 ml of a $Ba(OH)_2$ solution into a beaker. Add two drops of phenolphthalein solution. Point out that the pink color indicates a basic solution. Test the solution with pH paper.
B. Pour 15 ml of H_2SO_4 solution into the second beaker. Add two drops of phenolphthalein solution. Explain that phenolphthalein is colorless in an acid or neutral solution. Test with pH paper.
C. Test each of the solutions with the conductivity indicator system. The reading indicates the existence of ions in solution.
D. Leave the conductivity indicator in the H_2SO_4 solution. Using a dropper, add $Ba(OH)_2$ until there is no reading. (Neutralization should occur when equal volumes of the two solutions—prepared as directed—are combined. If barium hydroxide is exposed for long periods, some of it may react with CO_2 in the air and form a small amount of barium carbonate. If this happens, more $Ba(OH)_2$ solution will be needed to neutralize the acid.)

QUESTIONS

Encourage students to suggest possible answers to the following questions before you present explanations:

1. Why does the solution become cloudy after a base is added? (A salt is being formed; it is not soluble in water.)

2. Why does the solution lose the pink color? (The OH^- ions from the base combine with the H^+ ions from the acid to form water. Phenolphthalein is pink only when there are more OH^- than H^+ ions in solution.)
3. How might you explain the formation of a solid, with a model of ions? (The barium ions carry a positive charge, and the sulfate ions carry a negative charge. These unlike charges attract each other so strongly that the two kinds of ions form a compound that is an insoluble solid.)
4. What experimental evidence appears to verify this explanation? (The reading ceases, showing that there are not enough ions in the solution to maintain it as a conductor.)
5. What would happen if you added more base? Why? (The needle would move again because the base would contribute an excess of ions to the solution.)

PROCEDURES

E. Add extra base solution and observe that the precipitate remains but there is a reading on the indicator.

INVESTIGATION 5.4: Precipitation Reactions

When solutions of certain chemicals are mixed together, they react to form solids called *precipitates.* Precipitates may sink to the bottom of a mixture, or they may remain *in suspension,* giving the mixture a cloudy appearance. Precipitation reactions are useful in chemical analysis.

MATERIALS (per team)

- Test tubes, 8
- Stock solutions:
  - Sulfuric acid (H_2SO_4)
  - Sodium hydroxide (NaOH)
  - Sodium chloride (NaCl)
  - Barium chloride ($BaCl_2$)
  - Magnesium chloride ($MgCl_2$)
  - Potassium chloride (KCl)

PROCEDURES

A. In your notebook prepare a chart similar to Figure 5 • 7. Label the test tubes as follows: *NaCl/*H_2SO_4; *NaCl/NaOH;* $BaCl_2$*/NaOH;* $BaCl_2/H_2SO_4$; *KCl/*H_2SO_4; *KCl/NaOH;* $MgCl_2/H_2SO_4$; $MgCl_2$*/NaOH.* Into each tube pour small amounts (about 5 ml each) of the two solutions indicated on the label.

B. Observe the contents of each tube. On your chart indicate which combinations result in a precipitation reaction (formation of solid material). Also indicate which combinations remain clear.

Figure 5 • 7.

	NaCl	*BaCl₂*	*KCl*	*MgCl₂*
H_2SO_4				
NaOH				

INTERPRETATIONS

1. Equations for the combinations are listed below. In some of the combinations, precipitates were formed. In other combinations no evidence of a precipitate was observed. Which of the substances to the right of the arrows do you think formed precipitates?

a. $2NaCl + H_2SO_4 \longrightarrow Na_2SO_4 + 2HCl$

b. $NaCl + NaOH \longrightarrow NaCl + NaOH$

c. $BaCl_2 + H_2SO_4 \longrightarrow 2HCl + BaSO_4$

d. $BaCl_2 + 2NaOH \longrightarrow Ba(OH)_2 + 2NaCl$

e. $2KCl + H_2SO_4 \longrightarrow K_2SO_4 + 2HCl$

f. $KCl + NaOH \longrightarrow NaCl + KOH$

g. $MgCl_2 + H_2SO_4 \longrightarrow 2HCl + MgSO_4$

h. $MgCl_2 + 2NaOH \longrightarrow Mg(OH)_2 + 2NaCl$

2. Do you think ions from the lithium family would form a precipitate in a sulfuric acid solution? On what evidence do you base your answer?
3. Do you think that ions from the beryllium family would form a precipitate in a sulfuric acid solution? On what evidence do you base your answer?
4. Do you think that ions from the lithium family would form a precipitate in a sodium hydroxide solution? On what evidence do you base your answer?
5. Do you think that ions from the beryllium family would form a precipitate in a sodium hydroxide solution? On what evidence do you base your answers?

INVESTIGATION 5.4: Precipitation Reactions

(pages 120–121)

Major objectives for this investigation are (1) to illustrate that elements belonging to the same family tend to have similar chemical properties; (2) to provide information needed by students for Section Six, which involves the analysis of an unknown substance; and (3) to develop the ideas of balancing equations and conservation of matter.

MATERIALS

Prepare the following stock solutions before the investigation:

H_2SO_4 solution: slowly add 100 ml of concentrated sulfuric acid to 1000 ml of water.

CAUTION: *Concentrated sulfuric acid is highly caustic. In addition to this, it reacts with water to release heat. If sulfuric acid is added too rapidly to water, the reaction may produce sufficient heat to break the container. Never add water to any acid, since the heat produced may cause the small amount of water to boil, resulting in a spray of hot, concentrated acid. Always add acid to water at a moderate rate, i.e., 100 ml of acid added to 1000 ml of water in one or two minutes.*

NaOH solution: add 40 g solid NaOH to 1000 ml of water.

CAUTION: *NaOH is caustic.*

NaCl solution: add 60 g solid NaCl to 1000 ml of water.

$BaCl_2$ solution: add 230 g crystalline barium chloride ($BaCl_2 \cdot 2H_2O$) to 1000 ml of water.

$MgCl_2$ solution: add 100 g solid $MgCl_2$ to 1000 ml of water.

KCl solution: add 70 g solid KCl to 1000 ml of water.

If test tubes are not available, substitute glass microscope slides. If you do use slides, allow several drops of the designated solutions to come in contact on each one.

PROCEDURES

A. Labeling may be done in advance to save class time.

B. The absence or presence of a precipitate can be detected after only a few drops of each solution come in contact.

INTERPRETATIONS

1. The precipitates should be barium sulfate–$BaSO_4$; barium hydroxide–$Ba(OH)_2$; and magnesium hydroxide–$Mg(OH)_2$.

   Students should be able to identify these, since they have already observed (in Investigation 5.2) that hydrochloric acid and sodium chloride are soluble. By process of elimination, they should be able to identify the compounds that precipitate.
2. No precipitate. No ions of the lithium family formed a precipitate with sulfuric acid.
3. A precipitate might form. Magnesium ions did not form a precipitate with sulfuric acid, but barium did.
4. No precipitate. No ions in the lithium family formed a precipitate with sodium hydroxide.
5. A precipitate would form. Both barium and magnesium ions formed a precipitate with sodium hydroxide.

Not all members of the beryllium family form precipitates as readily as those given in this investigation. The general tendency is for the solubility of hydroxides of beryllium family compounds to increase as their atomic numbers increase.

Balancing Equations

When the weights of all materials mixed together before a chemical reaction occurs are compared with the weights after the reaction has occurred, the weights are always equal. Because of this we say that matter is neither created nor destroyed in chemical reactions. Since chemical equations are supposed to represent reactions, they should show the same amount of material before and after reactions occur. An arrow is used to represent the reaction occurring. Every atom shown on the left of an arrow (before the reaction) should also be shown on the right of the arrow (after the reaction). Chemical equations are said to be balanced when the number of atoms of each element to the left of the arrow equals the number of atoms of that element to the right of the arrow. Remember that *one* sodium ion will combine with *one* chlorine ion. So, if hydrochloric acid reacts with sodium hydroxide, we can write:

$$\mathrm{HCl + NaOH \longrightarrow NaCl + HOH}$$

But it takes *two* chlorine ions to combine with *one* ion of magnesium (Mg). So, if hydrochloric acid reacts with magnesium hydroxide, we must write:

$$\mathrm{2HCl + Mg(OH)_2 \longrightarrow MgCl_2 + 2HOH}$$

Chemical reactions occur in this way because different elements may form ions with different charges. Molecules are electrically neutral and must have equal amounts of positive and negative charge.

As a general rule, elements that tend to lose electrons combine with elements that tend to gain electrons. Thus both kinds of elements tend to achieve an electron grouping like that of an inert gas. Elements in the hydrogen, lithium, beryllium, and boron families tend to form compounds with elements in the nitrogen,

oxygen, and fluorine families. Since carbon may either lose or gain as many as four electrons, it forms compounds with most of the elements.

In pure form, the elements hydrogen, nitrogen, oxygen, and all of the members of the fluorine family form molecules that contain two atoms. These are diatomic (two atom) molecules, and they are written as follows: H_2, N_2, O_2, F_2, Cl_2, Br_2, I_2. You need to use this information so that you can balance chemical equations in which these elements are present.

Balancing equations is not necessarily difficult, but it does require that certain rules be followed. Consider the reaction between calcium (Ca) and oxygen (O_2):

$$Ca + O_2 \longrightarrow ?$$

Calcium is in the beryllium family and will react in a 1-to-1 ratio with elements in the oxygen family. An *incorrect* equation is:

$$Ca + O_2 \longrightarrow CaO_2$$

Calcium combines with oxygen in the ratio of 1 to 1, not 1 to 2. In other words, as far as we know, the compound CaO_2 does not exist. The correct equation for the combination of calcium and oxygen is as follows:

$$2Ca + O_2 \longrightarrow 2CaO$$

Before you can write a complete equation for a reaction, you must know the correct formulas for the compounds involved in the reaction.

Numbers slightly below and to the right of the symbol for an element or a *radical* (two or more elements that act as one) refer *only* to that particular element or radical. Examples: in a molecule of Na_2SO_4 there are two atoms of sodium, one atom of sulfur,

and four atoms of oxygen. In $Ba(OH)_2$, the number 2 refers to everything inside the parentheses, the (OH) radical. Therefore, the molecule contains one atom of barium, two atoms of hydrogen, and two atoms of oxygen.

A number to the left of, and level with, the symbols for a compound multiplies *all* atoms in the compound by that number. For example, 2HCl represents two molecules of HCl, or a total of two atoms of hydrogen (H) and two atoms of chlorine (Cl).

PROBLEMS

1. Examine each of the combinations listed in Interpretation 1. Determine whether or not equal numbers of each kind of atom appear on both sides of the arrow.
2. Predict the number of atoms of each element in the lithium family which would be needed to combine with one atom of oxygen.
3. Write balanced chemical equations for each of the following:

a. $Mg + Cl_2 \longrightarrow$
b. $2Li + Br_2 \longrightarrow$
c. $2Ba + O_2 \longrightarrow$
d. $Ca + S \longrightarrow$
e. $Ca + I_2 \longrightarrow$
f. $NaI + AgNO_3 \longrightarrow$
g. $Na_2S + BaCl_2 \longrightarrow$

Balancing Equations

(pages 122–124)

Students should now be able to balance simple equations and be ready to examine combining power. We do not suggest that the class spend an undue amount of time balancing equations. If they are able to grasp the fundamental manipulations necessary for balancing simple equations, they will be more comfortable with chemical equations and will gain a better understanding of the conservation of matter.

PROBLEMS

1. Equal numbers of atoms of each element appear on both sides of the arrow.
2. Two atoms of any element in the lithium family are needed to combine with one atom of any element in the oxygen family.
3. *a.* $Mg + Cl_2 \longrightarrow MgCl_2$
   b. $2Li + Br_2 \longrightarrow 2LiBr$
   c. $2Ba + O_2 \longrightarrow 2BaO$
   d. $Ca + S \longrightarrow CaS$
   e. $Ca + I_2 \longrightarrow CaI_2$
   f. $NaI + AgNO \longrightarrow NaNO_3 + AgI$
   g. $Na_2S + BaCl_2 \longrightarrow 2NaCl + BaS$

NOTE: *The combining power of silver (Ag) is not given in the modified periodic table. Students should question this omission rather than make a haphazard guess for Problem 3f.*

INQUIRY DEMONSTRATION: Observing Reactions and Writing Equations

Students should have an opportunity to write equations for reactions. They are more apt to understand the equations if they see the reactions occur. For each reaction you demonstrate, list the reactants on the board, showing ionic formulas where appropriate. Ask students to observe the reaction and guess what the products are. Next write formulas for the products on the board and have students write a balanced equation for the reaction. Stress that a balanced equation is one way to show conservation of matter in chemical reactions.

MATERIALS

$Pb(NO_3)_2$	Magnesium ribbon
NaBr	Aluminum foil
$CaCl_2$	Distilled water
NaOH	Beakers
$FeCl_3$	Test tubes
$Co(NO_3)_2$	Burner
$AlCl_3$	Tongs
Steel wool	Matches

These chemicals have been chosen to give colorful reactions. You may want to supplement this list with other chemicals. Use about 2 grams of each reactant in 100 ml of distilled water for each solution.

Reactants	*Ion Formulas*	*Products*
a. $Pb(NO_3)_2 + NaBr$	$Pb^{+2} + NO_3^- + Na^+ + Br^-$	$PbBr_2 + Na^+ + NO_3^-$
b. $CaCl_2 + NaOH$	$Ca^{+2} + Cl^- + Na^+ + OH^-$	$Ca(OH)_2 + Na^+ + Cl^-$
c. $FeCl_3 + NaOH$	$Fe^{+3} + Cl^- + Na^+ + OH^-$	$Fe(OH)_3 + Na^+ + Cl^-$
d. $Co(NO_3)_2 + NaOH$	$Co^{+2} + NO_3^- + Na^+ + OH^-$	$Co(OH)_2 + Na^+ + NO_3^-$
e. $AlCl_3 + NaOH$	$Al^{+3} + Cl^- + Na^+ + OH^-$	$Al(OH)_3 + Na^+ + Cl^-$

Balanced equations of precipitation reactions are as follows:

a. $Pb^{+2} + 2NO_3^- + 2Na^+ + 2Br^- \rightarrow PbBr_2 + 2Na^+ + 2NO_3^-$
b. $Ca^{+2} + 2Cl^- + 2Na^+ + 2OH^- \rightarrow Ca(OH)_2 + 2Na^+ + 2Cl^-$
c. $Fe^{+3} + 3Cl^- + 3Na^+ + 3OH^- \rightarrow Fe(OH)_3 + 3Na^+ + 3Cl^-$
d. $Co^{+2} + 2NO_3^- + 2Na^+ + 2OH^- \rightarrow Co(OH)_2 + 2Na^+ + 2NO_3^-$
e. $Al^{+3} + 3Cl^- + 3Na^+ + 3OH^- \rightarrow Al(OH)_3 + 3Na^+ + 3Cl^-$

Direct combination reactions are as follows:

Description	*Reactants*	*Products*	*Equation*
Steel wool held by tongs in a burner flame	$Fe + O_2$	FeO	$2Fe + O_2 \rightarrow 2FeO$
Magnesium ribbon held by tongs in a burner flame	$Mg + O_2$	MgO	$2Mg + O_2 \rightarrow 2MgO$
Aluminum foil held in a flame with tongs	$Al + O_2$	Al_2O_3	$4Al + 3O_2 \rightarrow 2Al_2O_3$

Compounds of Carbon

Elements can combine in various ways to produce thousands of different compounds. Salts are formed when metals combine with nonmetals. Other combinations of elements produce acids and bases. Of all the elements known to man, carbon is perhaps the most important for living things. All essential compounds in living matter contain carbon.

Perhaps your model of atomic structure can yield a clue about the importance of carbon to life. Carbon atoms can combine with each other and with atoms of other elements to form thousands of different compounds, including those that make up living matter. You have learned that when most atoms combine with others they tend to gain or lose electrons. The ions produced have electron groupings like those of inert gases. With the exception of helium, atoms of the inert gases have eight electrons in their outermost regions. (Some kinds of atoms share electrons instead of gaining or losing them. Carbon is an example of an element whose atoms share electrons.)

The atomic number of carbon is 6. A neutral atom of carbon has six protons in the nucleus and six electrons in the regions surrounding the nucleus—two electrons in the first region and four in the second, or outer, region.

If a carbon atom lost four electrons, it would have only two electrons remaining. It would then have the same electron arrangement as an atom of helium. On the other hand, if a carbon atom gained four electrons, it would have eight electrons in its outer region. This would be the same as the arrangement found in the inert gas neon. But carbon atoms do not appear to gain or lose electrons when they combine. Instead, they share electrons with other atoms. In this way they have an electron structure like an inert gas without forming ions.

To better understand the structure of carbon compounds, let us examine some simple formulas. For convenience we will concentrate only on the electrons in the outermost region. The carbon atom is represented by the letter *C* and four dots, one for each of the outer electrons (Figure 5 • 8).

Figure 5 • 8.
Carbon atom.

The hydrogen atom is represented by the letter *H* and one dot for the single electron (Figure 5 • 9).

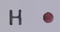


Figure 5 • 9.
Hydrogen atom.

Carbon combines readily with hydrogen to form a gas called methane, the chief ingredient of natural gas (Figure 5 • 10).

Notice the arrangement of "electrons" in methane. Because they share electrons with carbon, each hydrogen atom has two electrons in its outer region. This is the same electron arrangement as that of the inert gas helium. Similarly, carbon shares the electrons from the four hydrogen atoms and has a total of eight electrons in its outer region—the same electron arrangement as that of the inert gas neon. You may wish to review the partial periodic table (page 100) to see this more clearly.

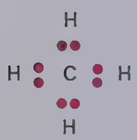


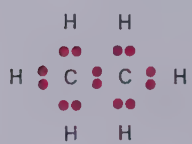
Figure 5 • 10.
Methane.

The *sharing* of electrons among atoms permits the formation of a greater number of compounds than does ionization—which requires the *transfer* of electrons. Since carbon atoms are able to share electrons with other carbon atoms, they can form a great variety of compounds. In addition to methane, there are many other compounds containing carbon and hydrogen—ethane, for example (Figure 5 • 11).

Ethane, like methane, is found in natural gas. Does each atom in ethane have the electron arrangement of an inert gas?

By means of chemical processes, carbon atoms and hydrogen atoms can be added, forming longer molecules (Figure 5 • 12).

Figure 5 • 11.
Ethane.



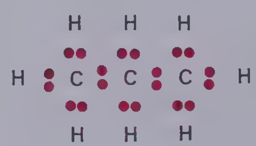


Figure 5 • 12.
Propane.

When three carbon and eight hydrogen atoms are bonded together, they form propane, a bottled gas that is often used when natural gas is unavailable.

It would be tedious to go on drawing dots for all the electrons each time we diagram a carbon compound. An internationally accepted system uses dashes between atoms to represent pairs of electrons. The diagrams in Figure 5 • 13 illustrate this convenient method.

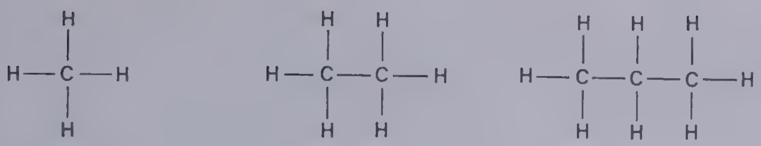


Figure 5 • 13. *From left to right,* methane, ethane, and propane.

Carbon Compounds in Living Things

Methyl alcohol and paraffin are examples of carbon compounds that burn easily and release energy. Neither is a food. Methyl alcohol is a poison, and no organism (with the possible exception of a few bacteria) can break down the molecules of paraffin. Living organisms also "burn" food and carry on many chemical reactions.

Sugar is a nutritious food for many animals. But what is sugar? There are many kinds, and the names of some of them may be familiar to you: cane sugar, beet sugar, malt sugar, corn sugar, and grape sugar. These names simply indicate the source of the sugar. They tell you nothing about the *structure* of the sugar molecule. Cane and beet sugars are both sucrose, having the formula $C_{12}H_{22}O_{11}$. Corn and grape sugars are glucose, with the formula $C_6H_{12}O_6$.

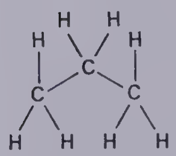
Fruit sugar is fructose, or levulose. Although its formula, $C_6H_{12}O_6$, is the same as that for glucose, fructose is much sweeter than glucose. But how can two compounds have the same formula and still be different? Formulas such as $C_6H_{12}O_6$ and $C_{12}H_{22}O_{11}$ show the number of different kinds of atoms that make up the molecules. But such formulas do not show how the atoms are arranged in molecules.

Suppose two men have equal quantities of bricks, sand, cement, and water. Could you guess what each man will build with his materials? One might build a sidewalk; the other, a fireplace. Each might use all of the materials and have nothing left over. The amount of materials used to build the sidewalk and the fireplace might be identical. Yet the form and use of the two struc-

tures would be very different. In the same way, fructose and glucose are made up of identical sets of atoms. But they have different characteristics because they differ in structure.

So far we have described carbon compounds as if the carbon atoms were arranged in perfectly straight chains. Better diagrams of models of a three-carbon compound and a six-carbon compound are shown in Figures 5 • 14 and 5 • 15.

Figure 5 • 14. Diagram of a propane molecule.



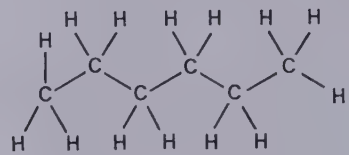
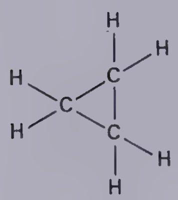


Figure 5 • 15. Diagram of a hexane molecule.

Figure 5 • 16. Cyclopropane



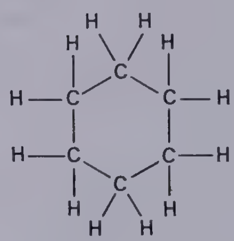
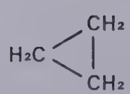


Figure 5 • 17. Cyclohexane.

The zigzag shape of these molecules is constantly changing. Under certain conditions, each of the end carbons may lose a hydrogen atom and form a ringlike structure, as shown in Figures 5 • 16 and 5 • 17.

A more convenient method of diagraming these two "ringlike" compounds is shown in Figures 5 • 18 and 5 • 19. For simplicity the bonds between carbon and hydrogen are not shown.

Figure 5 • 18. Cyclopropane.



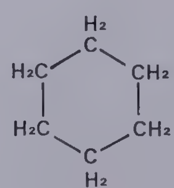
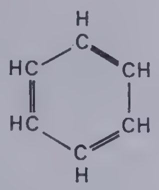


Figure 5 • 19. Cyclohexane.

Benzene, a ringlike compound somewhat similar to cyclohexane, is illustrated in Figure 5 • 20. Thousands of different drugs, dyes, explosives, and other chemicals are produced from benzene.

If carbon, hydrogen, oxygen, and nitrogen atoms are added to benzene in a certain way, a well-known compound results. Its name is *trinitrotoluene* (abbreviated TNT), a very powerful explosive. (Figure 5 • 21).

Figure 5 • 20. Benzene.



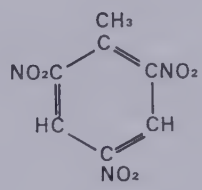


Figure 5 • 21. Trinitrotoluene.

Sugars also have ringlike structures. Examine and compare the molecules in Figure 5 • 22. We call these diagrams *structural formulas,* because they indicate the arrangement of atoms and their bonds. If you wish to count the numbers of different kinds of atoms in glucose and fructose, you should see that each compound has the same number of atoms.

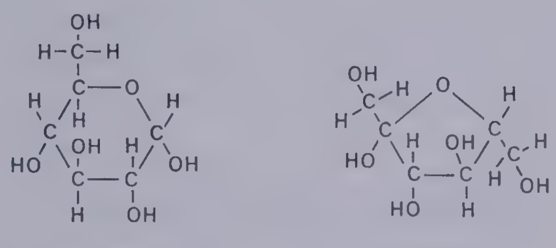


Figure 5 • 22. Structural formulas for glucose and fructose.

Suppose you tried to describe the difference between a horse and a donkey to a friend who had never seen either animal. It would take many words. Even then you might not be successful. But if you had a good picture of each animal, your friend could easily see the difference. This does not mean that he would be able to draw accurate pictures of horses and donkeys. But he

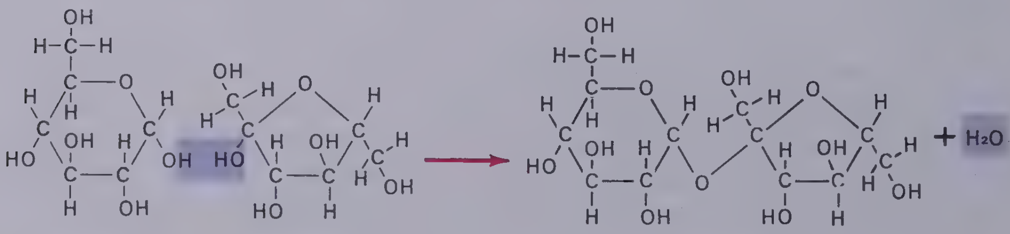
would have a much better understanding than if he had to rely only on your word description. For a similar reason, some structural formulas of chemical compounds are included in this book. It is not necessary to memorize these formulas. But it *is* important that you examine them carefully and see how they differ. Slight differences in structural formulas can cause great differences in the behavior of chemicals. For example, some bacteria can use glucose as a food, but not fructose. Other bacteria can use fructose, but not glucose. Man can obtain energy from both.

In addition to glucose and fructose, several other sugars have the formula $C_6H_{12}O_6$; these are called *simple* sugars. Some of these are important in the chemistry of living things. Sugars such as maltose and sucrose (table sugar) are formed by joining two simple sugar molecules. Figure 5 • 23 shows how the removal of an OH group and a hydrogen atom from two simple sugar molecules will bond the two together. A molecule of water is given off as a by-product.

Sucrose is called a *compound* sugar because it is made up of two simple sugars. Other compounds are formed by combining many molecules of simple sugars in long chains.

There are probably millions of different carbon compounds. In fact, thousands of new compounds containing carbon are produced every year. You have learned about just a few of the compounds carbon forms by sharing electrons. If you take a course in biology or chemistry, you will be able to study these compounds in greater depth.

Figure 5 • 23. Formation of sucrose and water from glucose and fructose.



glucose fructose sucrose

Compounds of Carbon

(pages 125–127)

Carbon atoms combine with atoms of other elements to form thousands of different compounds, including those that form living matter. To better understand the structure of carbon compounds, students examine simple formulas.

INQUIRY DEMONSTRATION: A Chemical Reaction with Sugar

(Teacher Only)

A complete analysis of sugar is impossible without complex equipment and advanced techniques. But it is possible for students to "discover" the presence of carbon in sugar and to guess reasonably that hydrogen and oxygen are also present. This demonstration should be performed before the structure of sugar molecules is discussed.

MATERIALS

Pyrex beaker, 125 ml, or small can
Table sugar
Stirring rod (glass or wood)
Concentrated sulfuric acid (H_2SO_4)

CAUTION: *H_2SO_4 is a strong acid—handle with care. Avoid breathing vapor given off during the reaction.*

PROCEDURES

Fill the beaker halfway with sugar. Add about 20 ml of concentrated H_2SO_4 and stir until the mixture has the consistency of thick paste. Allow students to observe the reaction. Students should see that the mixture of acid and sugar becomes a frothy black substance that expands out of the container while giving off what appears to be steam or some other vapor.

INTERPRETATIONS

1. Ask students to suggest what materials resulted from this reaction. They are likely to suggest that the black material is carbon. If students do not suggest that the vapor is water vapor, introduce this

possibility. A partial equation might be written on the chalkboard as students offer their ideas:

$$\text{Sugar} + H_2SO_4 \qquad\qquad \text{Carbon} + H_2O + ?$$

Since sulfuric acid was added to sugar, the preceding equation is not complete. The presence of some H_2SO_4 in the vapor might be suggested because of the acrid odor evident after the reaction occurs. (The carbon mass will also contain some acid and should be handled with tongs.)

2. Have several students gently touch the container after the reaction has ceased. The container will be quite hot, indicating that heat energy was given off. Energy can then be included in the equation:

$$\text{Sugar} + H_2SO_4 \qquad\qquad \text{Carbon} + H_2O + \text{Energy} + ?$$

Since other compounds—undeterminable by methods available to you—are present, the class cannot complete the equation.

3. Stress that while sugar can be decomposed in this fashion, scientists cannot put it back together even if the same amount of heat is applied, because this reaction is not reversible.

ON YOUR OWN: Investigating Carbon Compounds

This study gives you an opportunity to investigate five carbon compounds. Find out as much as you can about them with the materials, equipment, and techniques used earlier in the course.

MATERIALS

Vinegar
Sugar
Oil
Starch
Alcohol

PROCEDURES

A. You are limited to only 2 grams of each substance. Carefully design experiments that will produce as much information as possible.
B. Write up each investigation you plan to attempt. Include the questions you are trying to answer. List the equipment you will need.
C. Check with your instructor before you begin laboratory work.
D. Keep complete records of all experimental results.

INTERPRETATION

What can you find out about these carbon compounds? Your report should include a description of all your procedures, results, and interpretations of those results.

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ON YOUR OWN: Investigating Carbon Compounds

(page 131)

This investigation is designed to give each student an opportunity to design methods of collecting data on five different carbon compounds —sugar, vinegar, oil, starch, and alcohol.

Place the samples (about 2 grams each) in small plastic or wax cups. One hundred fifty samples will be needed for a class of thirty. Have the samples on labeled trays so that each student can observe the compounds for a while before he begins his experiments.

A wide variety of experimental designs may be suggested. Check each for potentially harmful or dangerous procedures before approving a design.

Praise each student's experimental design even though you may be sure that no conclusive evidence will be gained. It is a successful design if the student learns that a particular experiment doesn't have to be run again.

Following are a few sample questions and the appropriate equipment that might be suggested:

INQUIRY: What does each compound look like?
What properties do they have in common?
How are they different?
MATERIALS: magnifier, slide, toothpicks

INQUIRY: Are the compounds soluble in water?
MATERIALS: distilled water, beakers

INQUIRY: Will they conduct a current?
MATERIALS: conductivity indicator, beakers, distilled water

INQUIRY: Are they acidic, basic, or neutral?
MATERIALS: litmus paper, distilled water, beakers

INQUIRY: Do they form precipitates when mixed?
MATERIALS: beakers

INQUIRY: Will they burn in air?
MATERIALS: teaspoon, Bunsen burner, ring stand, and ring

INQUIRY: When they evaporate, do they leave salts?
MATERIALS: dropper, slide, burner

INQUIRY: Will a spot on a paper towel travel up and separate into parts if a solvent is used?
MATERIALS: paper strips, water, alcohol, dropper, beaker

At the completion of an experimental design, ask each student to prepare a brief report of his findings. When all investigations have been completed, ask each student to report to the class one thing he discovered about the compounds.

You may have to help students determine which of the facts apply to all carbon compounds and which ones fit only the particular compounds they investigated. Allow conflicting reports to be resolved by the ultimate judge: an experimental test.

SUPPLEMENTARY MATERIALS

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FILM

The Story of the Modern Storage Battery. Bureau of Mines Film #225. Color. 27 min. This is excellent film to extend the section. Applications of the concepts of solutions, ionization, conductivity, acids, salts, and precipitates are shown. Available on free loan from the Bureau of Mines. 1400 Forbes Avenue, Pittsburgh, Pennsylvania 15213.

FILM LOOP

Identifying an Unknown Element. Inquiry in Physical Science, Interaction Film Loops. Chicago: Rand McNally & Co., 1972.

SUGGESTED ACTIVITIES FOR TESTING LABORATORY SKILLS AND TECHNIQUES

INVESTIGATION 5.1

Observe the probes of a conductivity indicator in a solution and determine whether the solution is conducting.

INVESTIGATION 5.1

Set up a group of jars containing distilled water and use a conductivity indicator to determine which jar also contains NaCl.

INVESTIGATION 5.2

Using litmus determine which jar in a group contains an acid solution.

SECTION SIX

Investigating a Compound

SECTION SIX

Investigating a Compound

(pages 133–144)

Preview

One objective of Section Six is to provide students with an opportunity to conduct what is for them original research. As in most research, more questions will be raised than answered. Emphasize this characteristic of scientific investigation so students will realize that science is a creative activity—a continuing search for truth, rather than a static body of facts and conclusions. The teacher is the key to success here. It is imperative that you do *not* give students answers prematurely.

A second objective of this section is to help students put together a set of chemical principles from the study of bluestone, which can be applied to an understanding of many chemical phenomena.

There should be frequent opportunities to stress careful technique, observation, and interpretation, as each of the investigations of bluestone develops.

If students are to become aware of the dynamic, open nature of science, they must learn to evaluate data and draw their own conclusions. In this way they may arrive at new knowledge through their own thinking. This is the essence of learning science through inquiry—a process by which students use their intellectual ability to the fullest in learning more about their environment.

The authors believe that a comprehensive study of one unidentified compound results in a greater understanding of chemical interaction than would a superficial study of many compounds. The unknown substance is bluestone, a commercial grade of copper sulfate. The substance is not identified for the student, since some students may look up the composition of bluestone instead of using their data to determine its composition. Bluestone is used because of the number and variety of fundamental chemical concepts that can be introduced with this substance. We suggest that you use the term *bluestone* to repre-

sent the compound throughout this section. As students learn about the substance, they will probably begin to call it *copper sulfate*.

Most of the investigations in this section are designed to help students do just that. They first try to determine if bluestone is an ionic compound by using a conductivity indicator. Students find that a solution of bluestone does conduct electricity. They are then asked to determine which ions are positively charged and which are negatively charged. In this way students apply what they learned in Sections Three and Five to the problems posed in this section.

Students are asked whether the greenish blue color is caused by negative or positive ions. Next they apply drops of electrophoretically separated bluestone solution, one taken from the negative side and one from the positive side, to a glass slide. Students add $BaCl_2$ (barium chloride) to each of the drops and are asked a number of questions that they should be able to answer.

We urge that you carefully look at each investigation before having students carry it out.

The next major investigation involves adding barium chloride to a crushed bluestone solution. By this time most students will have a reasonably good idea that bluestone is actually copper sulfate.

Additional investigations involve the energy given off (as heat) as water of hydration is added to anhydrous copper sulfate.

This series of investigations could be done on an individual basis, allowing each student to proceed at his own pace. While more equipment is required, such individualization may so stimulate students that the additional costs will be well worth while.

We urge that you do not disclose the name *copper sulfate* until nearly every student in the class assigns this name to the "unknown compound."

PLANNING AHEAD

Check the material lists for each demonstration and investigation to be sure you have the equipment and supplies on hand.

Investigation 6.1: Two solutions must be prepared.

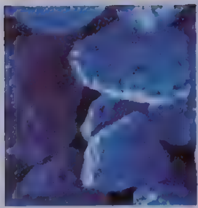
Investigation 6.2: One sample of solid bluestone must be provided per team.
One solution must be prepared.

Investigation 6.3: Obtain a container for the disposal of the copper sulfate.

LEARNING OBJECTIVES

Given the opportunity to inquire, to investigate, to interpret data, and to offer hypotheses about this section, students should be able to—

- Use techniques and reactions studied earlier to tentatively identify a limited number of unknown substances;
- Develop a logical sequence of procedures to investigate a limited number of unknown substances;
- Use a logical sequence of procedures to propose and refine hypotheses about the constituents of unknown substances;
- Demonstrate tests for solubility, ions in solution, acids and bases;
- Use suitable reagents to test for sulfate and hydroxide ions (or, alternatively, barium and magnesium ions);
- Recognize that color change may indicate that a chemical or physical change has occurred;
- Describe in words or equations each reaction observed in the study of bluestone;
- Deduce from data collected on these investigations the most probable composition of bluestone;
- Manipulate and use simple laboratory apparatus and chemical solutions (dialysis tubing, conductivity systems, various glasswares, battery and wires, acid-base indicators, various chemical substances, evaporation dish, and Bunsen burner).



In this section you have an opportunity to carry out a series of investigations in much the same way a scientist would. You will need to keep careful records of your observations and of the results of each investigation.

You have learned that compounds are combinations of elements. *Analysis* involves the taking apart, or the breaking down, of compounds so that the elements can be identified. Chemists are frequently faced with the problem of analyzing unknown compounds. In fact, analysis is one of the most important areas of chemistry. Some chemists are constantly analyzing various plant materials and soil samples in the hope of finding new drugs for the treatment of disease. Large city police departments often employ chemists to analyze unknown liquids that may be involved in a crime.

Various methods are used in analysis. They range from simple heating to highly technical processes that require complicated equipment.

INVESTIGATION 6.1: Concept of Analysis

In this investigation (and others to follow), you will be challenged to analyze an unknown compound. Since its color is a bluish green, we will call it *bluestone*. Your first task will be to see if it is composed of ions or if it is a compound whose atoms share electrons.

CAUTION: *"Bluestone" solution is poisonous if taken internally. The solution can stain clothing. If the solution is spilled in the eyes, immediately wash the eyes with tap water for several minutes. Call a physician.*

MATERIALS (per team)

Conductivity indicator
Bluestone solution, 50 ml
150-ml beaker or baby-food jar

Electrodes (paper clips and wires), 2
250-ml beaker or baby-food jar
Distilled water, 150 ml
Dialysis tubing, 20 cm
6-volt battery
Barium chloride ($BaCl_2$) solution, 10 ml
Medicine droppers, 3
Glass microscope slide or glass plate of similar size
Masking tape

PROCEDURES

A. Pour the bluestone solution into the 150-ml beaker. Insert the probes of the conductivity indicator into the solution and determine whether or not the solution conducts electricity. Record your observation.

INTERPRETATIONS

1. Did the solution conduct electricity? Are ions present in the solution?
2. From the results of the test, can you determine whether or not the color of the solution is caused by the presence of ions?

PROCEDURES

B. Assemble an apparatus like the one shown in Figure 6 • 1. Pour distilled water into the two halves of the dialysis tubing and into the 250-ml beaker. Pour 10 ml of bluestone solution into the distilled water in the beaker.

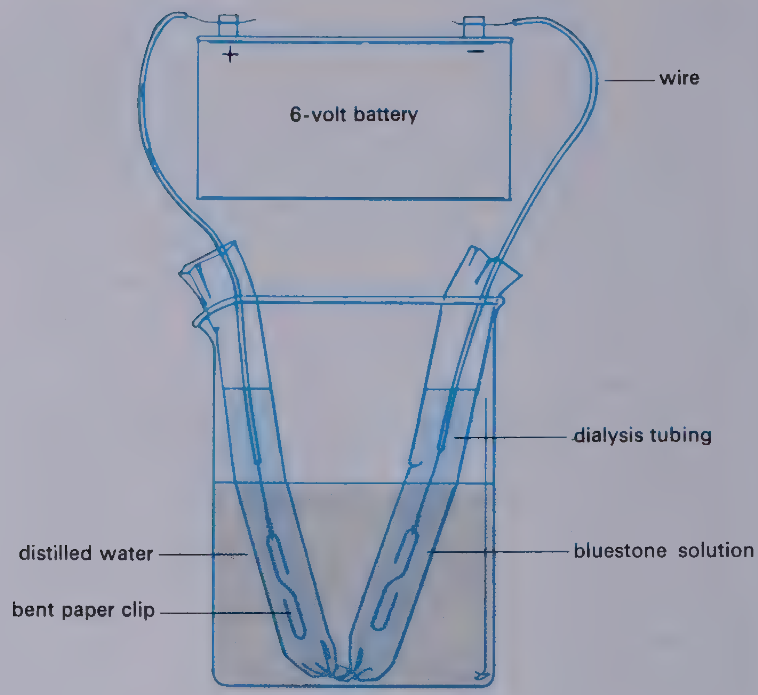
C. Before carrying out Procedure D, predict what the result would be if—

a. the color is caused by negative ions;

b. the color is caused by positive ions;

c. the color is not caused by ions at all.

Figure 6 • 1.
Setup for
Procedures B–D.



D. Insert an electrode into each half of the dialysis tubing and connect the electrode wires to the battery. Allow the test to continue for about twenty minutes before disconnecting the electrodes.

E. Write the letters *A* and *B* on pieces of masking tape at the ends of a glass microscope slide (Figure 6 • 2). Place a drop of barium chloride solution near each letter on the slide. Using a clean medicine dropper, obtain a sample of water from the dialysis tubing that was connected to the negative side of the battery. Add a drop of this water to the *A* drop of barium chloride solution on the slide. Using a clean dropper, obtain a sample of water from the dialysis tubing that was connected to the positive side of the battery. Add a drop of this water to the *B* drop of barium chloride solution. Then record your observations in your notebook.

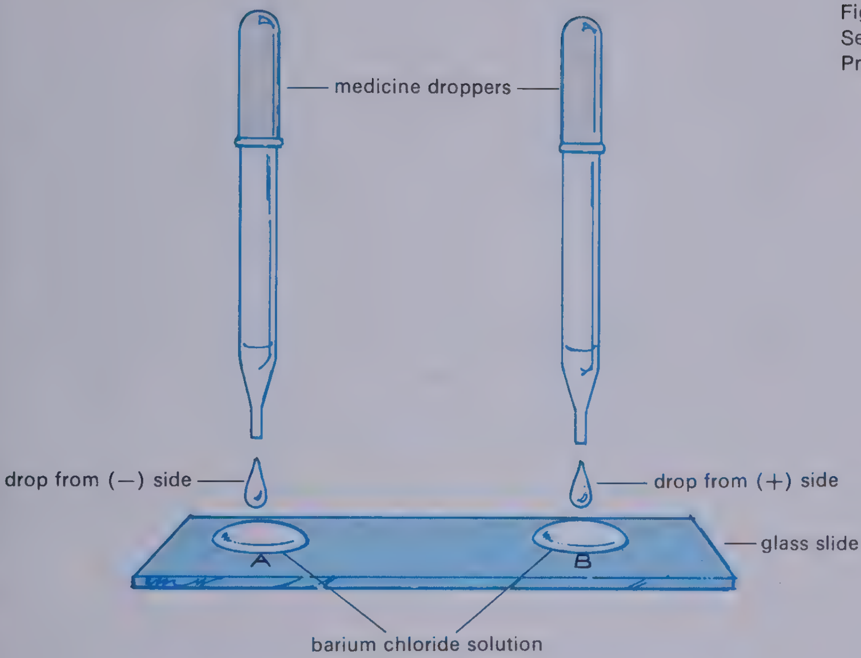


Figure 6 • 2.
Setup for
Procedure E.

INTERPRETATIONS

3. What can you conclude about the particles that give the solution a blue color?
4. What can you conclude about the particles that react with the barium chloride solution?

INVESTIGATION 6.1: Concept of Analysis

(pages 134–137)

In addition to gaining information about bluestone, students have an opportunity to apply techniques learned earlier. As a first step in the analysis, they use tests for ions and methods of separating and identifying ions.

MATERIALS

It may be possible to use one dropper bottle of $BaCl_2$ for the entire class. Test tubes can be substituted for the glass plate, but the tubes are more difficult to clean. Prepare a half liter of a saturated bluestone solution for the class.

PROCEDURES

A. Do not leave the probes of the conductivity indicator system in the solution for more than one or two seconds, to avoid corrosion.

INTERPRETATIONS

1. The conductivity test indicates that the solution contains ions.
2. There is no evidence that the substance which makes the solution blue is an ion. (The color, of course, is caused by the hydrated copper ion.) The purpose of asking the question is threefold: First, it points out the limitations of the conductivity test. Second, it emphasizes the need to separate observation from interpretation. Third, it points out the need for further investigation.

PROCEDURES

B. The electrode wires should not be connected to the battery until the apparatus is completely assembled and the students are ready to add the bluestone solution.

C. Possible student predictions:
   a. The solution in the dialysis tubing that contains the positively charged paper clip should become blue. The solution in the other half of the tubing should remain clear.
   b. The solution in the dialysis tubing that contains the negatively charged paper clip should become blue. The solution in the other half of the tubing should remain clear.
   c. If the blue particles are not charged, they will not be attracted to either half of the dialysis tubing, and there should be no difference in the appearance of the solutions in either half of the tubing.

D. The liquid should turn blue in the tubing containing the negative electrode.

E. A precipitate should form when the barium chloride combines with the drop of solution from the positive side. The negative sulfate ions are attracted to the positive electrode and repelled by the negative electrode.

INTERPRETATIONS

3. The particles that cause the solution to be blue must have a positive charge, because they are attracted to the negative electrode.
4. The particles that react with the barium chloride solution must be negatively charged, because they are attracted to the positive electrode.

INVESTIGATION 6.2: Gaining Additional Evidence

Your work in Investigation 6.1 should have given you some information about bluestone. You have completed one part of your analysis. Scientists are usually not satisfied with results of one or two investigations in analyzing a substance. Instead they carry out many different investigations so that they are sure their analysis is correct. And even then, they may be wrong.

MATERIALS (per team)

Baby-food jar with lid
Balance
Crushed bluestone (small baby-food jar, about half full)
A few pieces of bluestone
Graduated cylinder
Watch glass
Small test tubes, 2
Iron filings, 5 ml
Iron nail
Steel wool
Barium chloride solution
Litmus paper, red and blue

PROCEDURES

A. Pour 25 ml of water into a baby-food jar and add 20 g of crushed bluestone. Screw the cap onto the jar tightly. Shake the jar several times and note the color of the solution. Record your observations. Set the jar aside until the next time the class meets.

B. Examine several pieces of bluestone. Can you detect any similarity among them? Describe in your notebook the appearance of the bluestone, including color, shape, and other characteristics you think might be important. Make a sketch of a piece of bluestone in your notebook.

C. At the beginning of the next class period, observe the solution in the jar again. Did the bluestone dissolve?
D. Using a graduated cylinder, measure out 5 ml of the bluestone solution and carefully pour it into a watch glass. Save the remainder of the solution. Allow the watch glass to sit until the next time the class meets, so that the solution loses water by evaporation.

INTERPRETATIONS

1. Explain the reappearance of the bluestone in Procedure D.
2. Examine pieces of bluestone recovered in the watch glass. Compare them with the pieces examined in Procedure B. Are there any differences? If so, explain them.

PROCEDURES

E. Pour bluestone solution into a small test tube until the tube is about ⅓ full. Slowly add iron filings to the solution. Shake the test tube and record any changes. Continue adding filings and shaking the tube until no further change occurs.
F. Pour 5 ml of bluestone solution into a second test tube. Polish a nail with steel wool and place it in the tube. After five minutes, remove the nail and inspect it. Compare it with the color of a penny. Record your observations.

INTERPRETATIONS

3. What is the color of the solution in Procedure E, after iron filings are added?
4. What could have caused this color change?
5. Pour off only the liquid from the first test tube and examine the filings. Compare the nail with the material on the iron filings.
6. What element might be responsible for the color of bluestone?

PROCEDURES

G. Empty and rinse one of the test tubes with tap water. Pour bluestone solution from the baby-food jar into the tube until it is half full. Slowly add a solution of $BaCl_2$ (barium chloride) to the tube until signs of chemical reaction stop. Record your observations.

INTERPRETATIONS

7. Did the addition of $BaCl_2$ change the color of the bluestone solution? What substance might be present in the bluestone that could form a precipitate with barium?
8. Does the addition of $BaCl_2$ change your idea (Interpretation 6) about the material that is responsible for the color of bluestone?
9. Do you think bluestone solution is neutral, acidic, or basic? Record your prediction in your notebook.

PROCEDURES

H. Test the bluestone solution with litmus paper to find out if your prediction was correct.

INTERPRETATIONS

10. Does bluestone solution contain equal numbers of H^+ and OH^- ions, or does it contain more of one than of the other?
11. What do you think the precipitate formed by bluestone solution and $BaCl_2$ solution is?
12. You have partially analyzed a chemical compound. From the results of your experiments and from your observations, prepare a written description of bluestone, including the elements that you think make up the compound. Your statement will be judged on the basis of how carefully you have organized experimental results and observations.

INVESTIGATION 6.2: Gaining Additional Evidence

(pages 138–140)

Students observe and describe solid bluestone and compare a crushed sample with crystals grown by evaporation. They investigate some precipitation reactions of a bluestone solution in a continuing application of information and techniques learned earlier. Careful observations will support a tentative identification of bluestone as copper sulfate or copper hydroxide, and the test for acidity shows that it cannot be copper hydroxide.

MATERIALS

Crush enough bluestone so each team will have about 50 g. Some teams will use less than this, but there may be some spillage. The bluestone can be crushed with mortar and pestle or placed between two layers of heavy cloth, plastic, or paper toweling, and crushed with a hammer. Be sure to save some uncrushed bluestone.

Prepare the $BaCl_2$ solution before beginning the investigation by adding 23 g of crystalline barium chloride ($BaCl_2 \cdot 2H_2O$) to 1000 ml of water.

PROCEDURES

A. Divide your class into teams, keeping in mind the availability of glassware, balances, and other materials, for each team. The baby-food jars (or beakers) and watch glasses will be in use for at least two days and so cannot be used by more than one class.

B. Bluestone is crystalline cupric sulfate ($CuSO_4 \cdot 5H_2O$). The commercial material is often composed of coarsely crushed crystals; therefore, each piece of bluestone usually lacks the regularity of $CuSO_4 \cdot 5H_2O$ crystals. Students should make sketches of bluestone for later comparison with crystals of the same substance. The greenish blue color of bluestone will be compared with the deep blue color of the solution.

C. Unless the room temperature is well above 25°C, each team should use more bluestone than will dissolve in the given volume of water. Its solubility at room temperature is about 0.75 g per ml.

D. If petri dishes are available, use them in place of watch glasses. There is likely to be less spillage from petri dishes.

If your schoolroom is cool or if the humidity is very high, the water might not evaporate before the next class period. You can hasten evaporation by warming the dishes slightly. Do this by set-

ting the dishes on a box in which you have placed a lighted 100-watt bulb. Do not heat the dishes too much as the water of hydration will be driven off, leaving anhydrous copper sulfate—which is different in appearance from bluestone.

INTERPRETATIONS

1. When some of the water evaporates, there is not enough left to keep all of the bluestone in solution. Its particles then crystallize.
2. Students will find few, if any, complete crystals in the original material. The crystals formed as a result of evaporating water from the bluestone solution are likely to be small but complete. Crystals that form slowly are likely to be larger than those that form rapidly.

PROCEDURES

E. It may be necessary to dilute the saturated bluestone solution to reduce the amount of iron filings needed. The addition of iron filings to the solution results in the replacement of copper with iron. When almost all cupric ions have been replaced, the solution is colorless.

F. The nail is coated with a thin layer of copper. There may be some lessening in the intensity of the blue color of the solution.

INTERPRETATIONS

3. It is colorless.
4. It is not possible to anticipate hypotheses students may offer. Honor each until further investigation reveals additional information. Students may suggest that iron has caused the blue color to disappear, that iron absorbs blue color, or that iron has taken the place of whatever caused the blue color.
5. When students compare the residual material with iron, several may identify the material as copper.[T1] At this point an equation to explain the reaction might be developed as follows:

$$\text{Iron} + \begin{pmatrix}\text{some compound} \\ \text{of copper}\end{pmatrix} \longrightarrow \text{Copper} + \begin{pmatrix}\text{some compound} \\ \text{of iron}\end{pmatrix}$$

If students are able to suggest this possible relationship of iron to copper, they will be on the way toward an understanding of replacement reactions.

[T1] The purpose of including the experiment with the nail is to encourage students to conclude that the colored deposit on the iron filings is copper rather than rust.

6. Students will probably suggest copper. But if copper is responsible for the blue color in solution, it must be in a form quite different from that of the metal.

PROCEDURES

G. The role of precipitation reactions in elementary chemical analysis was introduced in Investigation 5.4. Some students should recognize the reaction with $BaCl_2$ as a possible test for sulfate or hydroxide ions, but they may need to refer back to their notes for that investigation.

$$BaCl_2 + H_2SO_4 \longrightarrow 2HCl + BaSO_4 \downarrow \text{precipitate}$$

or

$$BaCl_2 + 2NaOH \longrightarrow 2NaCl + Ba(OH)_2 \downarrow \text{precipitate}$$

INTERPRETATIONS

7. The color remains blue. Students should suggest that barium sulfate or barium hydroxide is the precipitate. They should now be able to suggest that bluestone contains copper and either sulfate or hydroxide ions.
8. If the sulfate or hydroxide ion is removed without a subsequent change of color in the solution, students who hypothesize that copper is responsible for the blue color should feel that their hypothesis is reinforced.
9. Any prediction should be accepted.

PROCEDURES

H. Blue litmus turns red, so the solution is acidic.

INTERPRETATIONS

10. The bluestone solution contains more H^+ ions than OH^- ions.
11. The precipitate is probably $BaSO_4$.
12. The extent and accuracy of each statement vary. Students should be able to complete the equation for replacement reaction to this extent:

Iron + Copper Sulfate ⟶ Iron Sulfate + Copper

The following additional points might also be mentioned:

a. Iron ions bond with water more strongly than do copper ions.
b. Copper is responsible for the blue color. Iron sulfate is nearly colorless, so replacing copper with iron in the copper sulfate solution removes the blue color.

c. Barium bonds more strongly with sulfate than does copper—thus, the following equation:

$BaCl_2$	+	$CuSO_4$	$\longrightarrow$	$BaSO_4$	+	$CuCl_2$
(barium chloride)		(copper sulfate)		(barium sulfate)		(copper chloride)

d. Apparently barium sulfate is not soluble in water, while barium chloride is. Both copper sulfate and copper chloride are soluble.

Encourage students to ask questions in their reports. As the course progresses, many of these questions will be resolved. Students should make increasing use of symbols rather than names when writing chemical equations.

INVESTIGATION 6.3: The Problem of Color

You have partially analyzed a compound. In the process you have experienced some of the successes and failures that are typical in scientific research. You have tried to establish a reasonable idea to account for the color of bluestone. Other properties of bluestone, studied in this investigation, should add to your understanding of chemical interaction.

MATERIALS (per team)

- Crushed bluestone
- Evaporating dish
- Ring stand and ring
- Wire gauze
- Bunsen burner or alcohol burner
- Matches
- Pyrex test tube
- Test tube holder

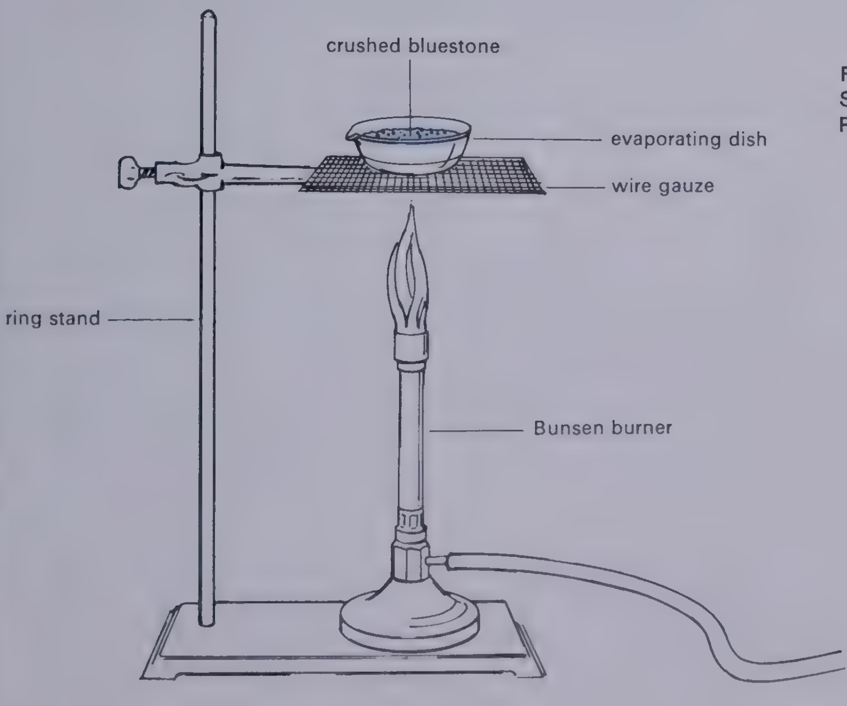


Figure 6 • 3. Setup for Procedure A.

PROCEDURES

A. Place a small amount of crushed bluestone in a clean evaporating dish. Set up the apparatus shown in Figure 6 • 3. Heat the dish of bluestone over the burner until the material shows a definite change. Allow it to cool. Record your observations.

B. Place a small amount of powdered bluestone in the bottom of a clean Pyrex test tube. Place the tube in the holder and heat gently until no further changes occur. Record your observations in your notebook.

INTERPRETATIONS

1. Compare and explain results observed in Procedures A and B.
2. From these observations, evaluate your idea about the material responsible for the color of bluestone. Under what conditions does bluestone show a blue color?
3. Is the white substance still bluestone?
4. What substances do you believe are in bluestone? What questions about the structure of bluestone still seem unanswered?

INVESTIGATION 6.3: The Problem of Color

(pages 141–142)

From the results of Investigations 6.1 and 6.2, students are likely to conclude that the color of bluestone results from the presence of copper. This is correct only under certain conditions. If students have not already done so, ask the question, "Why isn't a copper penny blue?" In Investigation 6.3, it will be seen that the anhydrous form of cupric sulfate is white. *Do not explain this to students yet.*

CAUTION: *Provide a waste container for disposing of the anhydrous copper sulfate. Do not let students wash it down the sink or throw it in the wastepaper basket.*

PROCEDURES

A. As cupric sulfate is heated and changes from blue to white, the loss of water is not readily apparent. Students may suggest several hypotheses to explain this change: heating causes a rearrangement of atoms; the blue color is vaporized; hot bluestone is white, while cool bluestone is blue; and so forth. Honor each hypothesis, but refrain from discussing any in too great detail until Procedure B has been completed. If students mention that bluestone seems to "melt" before changing color, acknowledge this as a good observation but avoid further discussion.

B. Heating bluestone in a test tube should reveal the presence of water, which will condense on the sides of the tube. An important point here is that the completeness of an observation often depends on the circumstances of the event. In this case, the narrow walls of a test tube allow water to condense and be observed, while little, if any, water will condense on the relatively low walls of an evaporating dish. It is conceivable that a researcher might never suspect the role of water in the "bleaching out" of bluestone if he always placed bluestone in a flat dish before heating. Stress that discovery of a new phenomenon may be obscured because of chance factors like this in experimental design.

INTERPRETATIONS

1. Students should observe the presence of water droplets on the sides of the test tube. Since the blue color disappears as the water evaporates, water could be thought to have a role in the physical appearance of bluestone.

2. Students might hypothesize that bluestone is blue only when water is present. Or they might suggest that some other change occurs as the result of heating. Investigation 6.4 should clarify this point. Ask how the presence of water on the sides of the test tube can be explained. Suggest that if water is present, it might be revealed by crushing bluestone into a fine powder. Encourage students to try this. Of course such a process fails to yield water. Ask, "Where, then, does the water originate?" Develop the concept that water is necessary for bluestone to be blue. Water may be involved in the *structure* of solid bluestone in some way. Ask students to suggest a model that could explain the presence of water in a form that is not directly evident.

   The ability of students to construct this model will depend on how well they understand the structure of matter presented earlier in the course. Since water is not visible in bluestone, it could have formed a chemical bond with the $CuSO_4$. Since heating releases water, the water-$CuSO_4$ bond must be weaker than the other bonds that maintain the structure of copper sulfate.

   Encourage students to develop the concept of water of hydration, in which a compound forms a relatively weak chemical bond with water.
3. Since the white substance no longer has the properties of bluestone, we must assume it is different.
4. This question is designed to stimulate discussion. Encourage students to offer suggestions, but withhold answers until Section Six has been completed.

INVESTIGATION 6.4: Role of Energy

Investigations 6.1 through 6.3 should have revealed a relationship between the structure of bluestone and its color. Investigation 6.4 points to still another kind of chemical interaction, the role of energy in chemical reactions.

MATERIALS (per team)

- Crushed bluestone
- Pyrex test tube
- Bunsen burner or alcohol burner
- Test tube holder
- Test tube rack (or a small beaker or baby-food jar to support the tube while it cools)
- Medicine dropper

PROCEDURES

A. Place a small amount of bluestone in a clean Pyrex test tube. Place the tube in the holder and heat until the bluestone turns white. Allow the tube to cool.

B. Hold the tube containing the white form of bluestone exactly as shown in Figure 6 • 4. Slowly add water, drop by drop, until a definite color change occurs. Note anything that happens as you add water.

Figure 6 • 4. Carrying out Procedure B.

INTERPRETATION

In addition to a change in color, another kind of change occurred as water was added. Describe this change fully. Try to state an idea that will explain this additional change.

ON YOUR OWN: Moles of Water in Bluestone?

Data gathered in Investigations 6.3 and 6.4 suggest that water is involved in the structure of bluestone. If a small amount of water evaporates when a sample of bluestone is heated, part of the sample is blue and part is white. If enough water is added to bluestone, the bluestone will dissolve. Your problem is to determine the ratio of water molecules to molecules of the white material in a pure sample of bluestone crystals. Experiments have shown that the molecular weight of the white material, obtained by heating bluestone, is 160 grams per mole.

Design an experiment that will give you the data needed to calculate the number of water molecules that combine with one molecule of the white material to form pure bluestone crystals. Describe the experiment in your notebook. *Check with your teacher before attempting the experiment.* To make your calculations significant, you must perform weighings with as much precision as possible.

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INVESTIGATION 6.4: Role of Energy

(pages 143–144)

The major purpose of this investigation is to provide evidence that the hydration of $CuSO_4$ involves an energy change. Students will note that the test tube becomes quite hot. This increase in temperature is accompanied by a return of the typical color of bluestone.

PROCEDURES

A. Warn students not to touch the test tube until it has cooled. Stress that burns from hot glassware are both painful and unnecessary.

B. The water should be added carefully and sparingly. Students may not notice the heat evolved if too much is added.

INTERPRETATION

Evidence of heat should support the concept that a chemical bond exists between $CuSO_4$ and H_2O. Energy is always given off when substances combine to form more stable products.

ON YOUR OWN: Moles of Water in Bluestone?

(page 144)

Specific instructions have been omitted deliberately so students will be challenged to work out methods for determining the number of water molecules of hydration in a molecule of $CuSO_4 \cdot 5H_2O$. The teacher has maximum latitude in encouraging student ingenuity. You cannot expect all of your students to devise an adequate or successful plan, even after class discussion. It may be necessary for you to work through the experiment and calculations with some students. A design for the experiment follows:

MATERIALS (per team)

Balance, accurate to 0.01 g (The Torbal or the Ohaus Centogram balance is recommended.)
Crushed bluestone
Evaporating dish
Bunsen or alcohol burner

PROCEDURES

Weigh an evaporating dish and record its weight to the nearest hundredth of a gram. Weigh out approximately 3 grams of bluestone. Record the weight to the nearest hundredth of a gram. Dehydrate the bluestone in an evaporating dish and allow it to cool. Weigh the evaporating dish plus the dehydrated bluestone (white residue); subtract the weight of the evaporating dish. The weight of hydrated bluestone minus the weight of the dehydrated bluestone equals the weight of the water in the hydrated bluestone.

TYPICAL DATA

Weight of evaporating dish	48.05 g
Weight of evaporating dish + bluestone	50.55 g
Weight of evaporating dish + white residue	49.65 g

SAMPLE CALCULATION:

Weight of Water Lost

$$\begin{array}{r} 50.55 \text{ g} \\ -\ 49.65 \text{ g} \\ \hline 0.90 \text{ g} \end{array}$$

Moles of Water Lost

$$\frac{0.90 \text{ g}}{18.00 \text{ g/mole}} = 0.05 \text{ moles}$$

Weight of White Residue

$$\begin{array}{r} 49.65 \text{ g} \\ -\ 48.05 \text{ g} \\ \hline 1.60 \text{ g} \end{array}$$

Moles of Residue

$$\frac{1.60 \text{ g}}{160.00 \text{ g/mole}} = 0.01 \text{ moles}$$

The number of water molecules per molecule of white residue is equal to the moles of water in the sample divided by the moles of white residue.

$$\frac{0.05}{0.01} = \frac{5 \text{ moles of water}}{1 \text{ mole of white residue}}$$

$$\frac{5 \times 6.024 \times 10^{23} \text{ molecules of water}}{1 \times 6.024 \times 10^{23} \text{ molecules of white residue}} = \frac{5 \text{ molecules of water}}{1 \text{ molecule of white residue}}$$

Experimental error and the limitations imposed by the equipment will undoubtedly cause variation in results. If data are gathered from all teams, the average should approximate a 5-to-1 ratio.

INTERPRETATION

Ask students to suggest ways in which the technique might be improved, so that results would be more accurate.

SUPPLEMENTARY MATERIALS

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SUGGESTED ACTIVITIES FOR TESTING LABORATORY SKILLS AND TECHNIQUES

INVESTIGATION 6.1

With a medicine dropper remove some liquid from dialysis tubing and use $BaCl_2$ to test for the presence of sulfate ions.

INVESTIGATION 6.2

Prepare a solution of specified concentration (e.g., 1 g of NaCl per 10 ml of solution).

INVESTIGATION 6.2

Read the volume of water in a graduated cylinder.

INVESTIGATION 6.4

Heat an object in a test tube to demonstrate the proper use of a burner and test tube holder.

ON YOUR OWN

Use a balance to weigh an object.

SECTION SEVEN

Developing the Meaning of Measurement

SECTION SEVEN

Developing the Meaning of Measurement

(pages 145–170)

Preview

From the beginning of this course we have stressed the concept that science is not the embodiment of complete or absolute truth. In this section students should realize that it is impossible to make *absolutely* accurate measurements, no matter what the devices or standards used.

Today we take systems and standards of measurement for granted. Yet, if three persons are asked to determine the area of a table by using a yardstick, three different answers will probably result. One purpose of this section is to make students more aware (and more tolerant) of the persistence of human error.

Another purpose is to demonstrate the usefulness of standard units of measurement. Without convenient, communicable, and widely used systems of measurement, early man was severely limited in his ability to deal with basic problems of trade, ownership, construction, travel, and any other activity that required reasonably accurate measurement.

The reading portions of this section should also permit students to develop an understanding of the general concept of measurement as it has evolved from ancient to modern times.

The section begins with speculation about how Cro-Magnon man might have made the crude measurements necessary for his existence. The further question is raised whether animals other than man can count. Certain observations indicate that some animals have a kind of "number sense." Again, this is speculation.

The earliest known standard measuring device was the cubit—the distance from the point of the elbow to the tip of the longest finger. This forearm (cubit) measuring rod was usually based on the length of the forearm of a king or pharaoh. Students are asked to construct their own cubit rod (or stick) based on the length of their own forearms. They are later asked to determine the area of a desk or table

in square cubits. The purpose of this investigation is to place students in a situation that gives them a chance to experience the problems of measurement in ancient times.

The history of measurement is then briefly described (pages 151–154) from ancient to modern times. Students are asked to explain how the early Egyptians were able to determine the height of a tall tree using a stick. This is another "On Your Own" investigation which lends itself to individual study.

Up to this point in the course, students have not been given specific details about the differences between the English and metric systems. In Investigation 7.2 (pages 154–155), students study both systems of linear measurement. The series of problems which follow enable students to evaluate the two systems and to determine which system they prefer to use.

Students are then asked to measure the length and width of a desk or table and to determine the area. They use cubits and English and metric units.

An additional "On Your Own" investigation gives students an opportunity to invent their own measuring devices. This can be done by individual students or by two or more working together.

Other investigations deal with measuring solids and liquids, and learning mass-to-volume relationships (density).

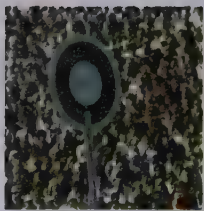
One "On Your Own" investigation on density provides for further individualized study.

LEARNING OBJECTIVES

Given the opportunity to inquire, to investigate, to interpret data, and to offer hypotheses about the activities in this section, most students should be able to—

- Properly use such laboratory measurement devices as millimeter rulers, graduated cylinders, overflow cans, gram scales;
- Convert millimeter measurements to centimeters or meters (should be able to express millimeters or centimeters as decimal fractions of a meter, etc.);
- Compare experiences using the English and metric systems of measurement and explain the benefits of each system;
- Calculate and use averages of varying measurements of the same phenomenon or object in order to arrive at closer estimates of measurements;
- Recognize the possibility of experimental and measurement errors in the interpretation of data;
- Measure and calculate area and volume;

- Explain and recognize systematic and random (experimental) errors;
- Accurately determine or measure the weight in grams of a variety of substances;
- Find the volumes of an assortment of cubes and irregularly shaped objects;
- Express simple mathematical relationships in graphic form;
- Determine mass-to-volume relationships for an assortment of liquids;
- Determine mass-to-volume relationships for various irregular objects;
- Offer hypotheses to explain the changing densities when mixtures evaporate;
- Design their own methods to determine weight-to-volume relationships for irregularly shaped objects;
- Estimate the approximate density of a floating object by inspection.



Science is often described as man's attempt to understand and explain what he observes through his senses. One of the first steps in any scientific activity is observation. Observation often leads us to ask why, how, or what. If we ask no questions, we have no science.

Sometimes we may answer questions by making additional observations: What color is it? What does it feel like? Does it make a noise? Does it have an odor or a taste? Such questions can be answered by using one or more of our senses.

But consider another type of question: How big is it? How heavy is it? How hot is it? How fast is it moving? Through the senses, you may be able to make rough guesses about such things as size, weight, temperature, and speed. But unless you *compare* your observations with something that is familiar to others, you cannot describe size, weight, and so forth, in a way that has meaning. Accurate observations and the communication of them to others require some standards of measuring.

Do you suppose Cro-Magnon man measured things? What did he need to measure? What might he have used as standards of measure? All that was available to him were the natural objects of his environment—himself, the sun, trees, stones, and so forth. What did he do when new clothing was needed? Do you suppose an animal was killed and skinned, and its skin was held up to a member of the tribe? In this case the human body was the standard of measure.

When a hunter proved the value of a particular type of spear, other hunters might have wanted one like it. The spear could have been used as a standard for making other spears. When these spears became widely used, perhaps the chief of the tribe announced that "the spear" was to be the measurement standard.

A large, heavy spear could not be used to advantage in hunting small animals; perhaps the weapon needed for this was a stone. How could Cro-Magnon man decide on the size of stone? By hefting it in his hand? By the feel and shape of it? Through trial and error he probably arrived at the right kind of stone for killing an animal of a certain size and a certain distance away.

Figure 7 • 1. Cro-Magnon men selecting stones to be used for killing birds.

Number Sense

Some ability to understand differences in numbers appears to be present in many animals. This ability has been called *number sense*. If one of her kittens is removed, a mother cat will usually show that she is aware of the loss.

A farmer reported an interesting example of number sense in a crow that often roosted near his barn. If the farmer went into his barn, the crow would fly away and not return until the farmer came out. If the farmer and his hired man entered the barn, the crow would leave and not return until *both* men came out. If three men went in and then came out one at a time, even with long waits in between, the crow would not return until all three had come out.

Could the crow count? What else might have explained the crow's ability to keep track of the number of men in the barn? Perhaps the crow could smell or sense in some other way that a man was still inside. The farmer decided to test his idea. He went

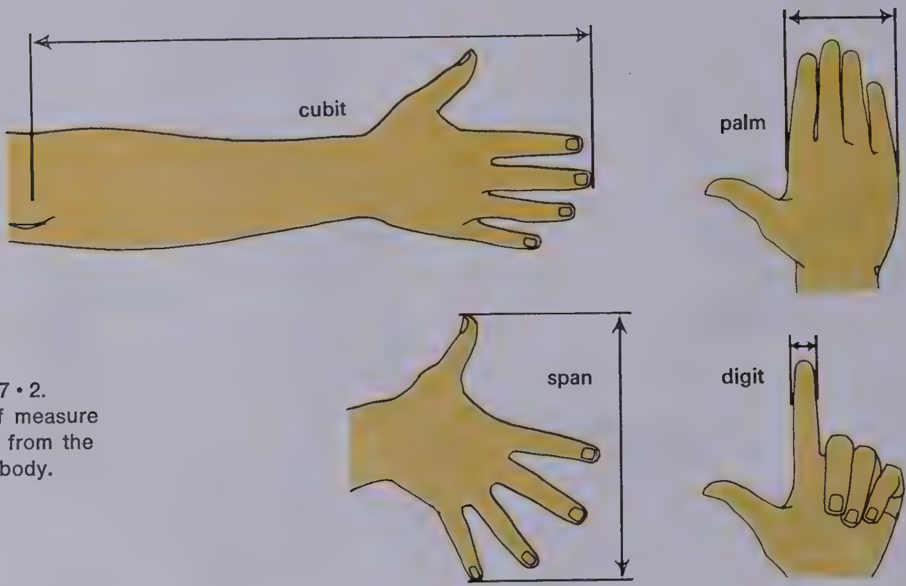


Figure 7 • 2. Units of measure derived from the human body.

into the barn as usual. But the hired man sneaked around to the back without the crow seeing him and entered through another door. The crow flew away and returned when *one* man left through the front door!

Further testing indicated there was a limit to the crow's number sense. When as many as four persons entered the barn and left together, in a combination of three and one, or two and two, the crow would return. But when five or more persons entered, the bird apparently lost count and would return even if all but one person remained in the barn.

Some system of counting was necessary before man could develop a system of measurement. We do not know when he learned to count. But it is reasonable to assume that early man at least had the ability to keep track of things by number sense.

Was early man concerned with distance? We can only guess that he measured distance with steps or paces. Long distances could have been measured by keeping a count of how many "suns" rose and set during a given trip.

When man moved from caves into dwellings he himself had built, there was a need for measurement during construction. Words were needed to express quantity, size, and distance. Eventually by using the most convenient object in his environment, man developed the following units of measurement:

Cubit—the distance from the point of the elbow to the tip of the middle finger.

Span—the distance from the tip of the thumb to the tip of the little finger when the fingers are spread out.

Palm—the breadth of the palm at the base of the four fingers.

Digit—the breadth of the index finger or middle finger.

These measurements—particularly the cubit—were important to the early Babylonians, Hebrews, and Egyptians. If one person was doing all the measuring on a job, the cubit was always the same. But when temples, pyramids, and other large structures requiring the efforts of many men were being built, identical units of measure had to be used.

More precise units of measure were needed, and the measuring rod came into use. The exact length of a rod was usually decided by the local king or pharaoh. One-cubit measuring rods were produced (Figure 7 • 3).

Figure 7 • 3. *Top:* Five thousand years ago, the Egyptians established the first standard of linear measurement, the cubit. The cubit (meaning "forearm") was equivalent in length to the pharaoh's forearm—about 20.6 inches. The Royal Cubit, *shown here,* was made of black granite and divided into spans, palms, digits, and fractions of digits. It was placed in the custody of the royal architect. *Bottom:* Wooden cubit rods were made from the Royal Cubit and were used in building Egypt's great pyramids, tombs, and temples.

INVESTIGATION 7.1: Constructing a Cubit Stick

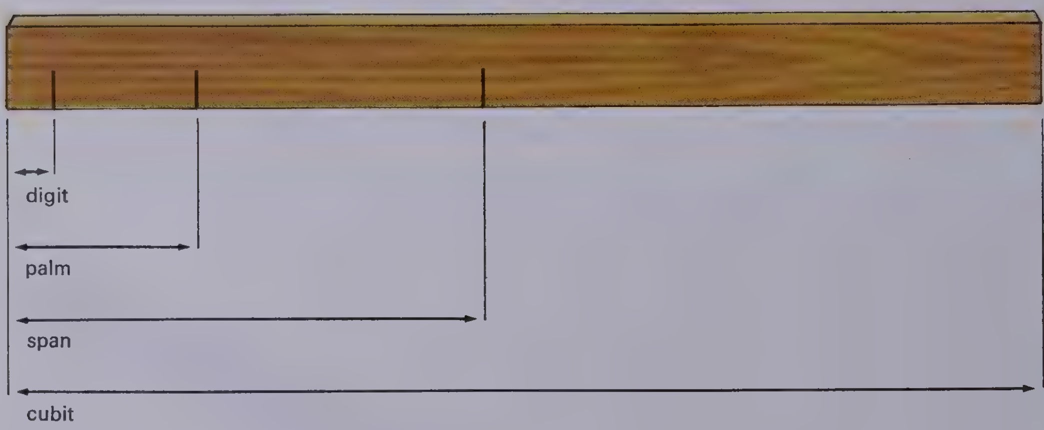
We have discussed how people in early civilizations used the cubit, palm, span, and digit, to provide a means of measurement. Your task in this investigation is to construct a cubit stick based upon the distance from your own elbow to the tip of your finger. Further subdivide the cubit stick into palm, span, and digit units. See Figure 7 • 4.

This investigation should be done at home or after school. The only material you will need is a stick equal to a cubit measured on your own forearm from the tip of your elbow to the end of your finger. You must *not* use a ruler as an aid.

When you have finished your cubit stick, compare it with those made by others in your class.

Save your cubit stick for use in Investigation 7.3.

Figure 7 • 4. A cubit stick.



INTERPRETATIONS

1. Is your cubit stick the same as those prepared by other students? If not, explain why there is a difference.
2. How does this investigation illustrate some of the difficulties encountered by people of earlier civilizations in their attempts to make accurate measurements?

INVESTIGATION 7.1: Constructing a Cubit Stick

(page 150)

Constructing a cubit stick is not only fun, it also illustrates the variation in this type of measuring device due to the physical differences in individuals.

These cubit sticks will be used in Investigation 7.3, and each should be labeled with the student's name.

One purpose of this investigation is to show how difficult it must have been for builders in early civilizations to construct buildings and monuments so that such structures would be both uniform and pleasing to the eye.

MATERIALS

Insist that students avoid the use of rulers and that they construct their cubit sticks much in the same manner as the ancient builders.

Students should find their own sticks for construction of cubit sticks.

INTERPRETATIONS

1. There should be a considerable difference between measurements, since at this age, growth patterns vary to a considerable degree.
2. If different individuals used their own body measurements, each village would have building dimensions slightly different from those of other villages.

From Ancient to Modern Measurement

As the power of Egypt declined, the Roman Empire was expanding. The early Romans were the first to measure distance in *miles*. *Mile* is short for the Latin words *mille passus*, meaning thousand paces. The Romans borrowed the term *foot* from the Greeks and divided the foot into *inches* (the breadth of the thumb). The measurements of the Roman foot and inch are not quite the same as ours.

It is easy to see how the foot was derived, but like other body measurements, it varied from one man to another. So the Romans used measuring rods. These were kept in the temples. With the fall of the Roman Empire, many of these temples were destroyed, and the measuring rods were lost. With the breakdown of central government, the small towns and hamlets had to use their own standards of measurement.

In western Europe, local lords and barons came into power, and the strongest among them became kings. These monarchs set their own standards of measure. They still used body measurements—often the king's personal measurements. King Henry I of England (1068–1135) defined the *yard* as the distance from the tip of his nose to the end of his thumb when his arm was fully extended to one side. A system of weights was developed with stones and crude balances. The term *stone* is still used in England today as a standard weight (1 stone equals 14 pounds).

In the latter part of the eighteenth century, leading citizens of the new Republic of France decided there was a need for more precise measures—measures that would not be dependent on the length of someone's forearm or some other variable. The standards would be used throughout France and made available to other nations.

It was decided that the basic unit of linear measure would be one twenty-millionth of the length of the meridian that passes through Paris. (A meridian is an imaginary half circle on the earth's surface, extending from the North Pole to the South Pole. See Figure 7 • 5.) This distance was the first *meter*. In 1791 surveying operations were begun to determine the length of this unit.

Unfortunately an error was made in the calculations, and a new meter had to be established. Finally the correct distance was carefully measured off on a bar of platinum-iridium; two marks to indicate the exact length of the standard meter were engraved on it. This bar was called the International Prototype Meter. It was kept under triple lock and key in the Pavillon de Bretueuil, at Sevres, France, the home of the International Bureau of Weights and Measures. Carefully made, certified copies of this meter were given to countries using the new standards in the metric system.

In the twentieth century, as industry and science began to require more accurate measurements, a new official standard was adopted. In 1960 the General Conferences on Weights and Measures met in Paris and adopted an official *standard meter* based on a certain wave length of light.[1] Using complex equipment, it is now possible to make measurements of length accurate to one part in a hundred million.

Today we have highly accurate standards for weighing and measuring objects. Yet we still use body measurements. We still pace off distances, and people still estimate the yardage in a piece of material by using an approximation of King Henry's yard.

In future investigations, you will learn more about the metric system and its use. Appendix C provides tables for your use in converting measurements from the English to the metric system.

All standards of weights and measures are arbitrary. Somewhere, at some time, someone simply decided that a certain unit of measure would be useful. If it was convenient to use and to duplicate, it stood a good chance of becoming a standard unit.

PROBLEMS

1. Today the metric system of measurement is used in all parts of the world for most scientific work. Why do you think most scientists, regardless of nationality, agree on the use of one system of measurement?

[1] The nature of light waves will be considered in Section Twelve.

Figure 7 • 5.
One twenty-millionth of the length of the Paris meridian was the first standard meter.

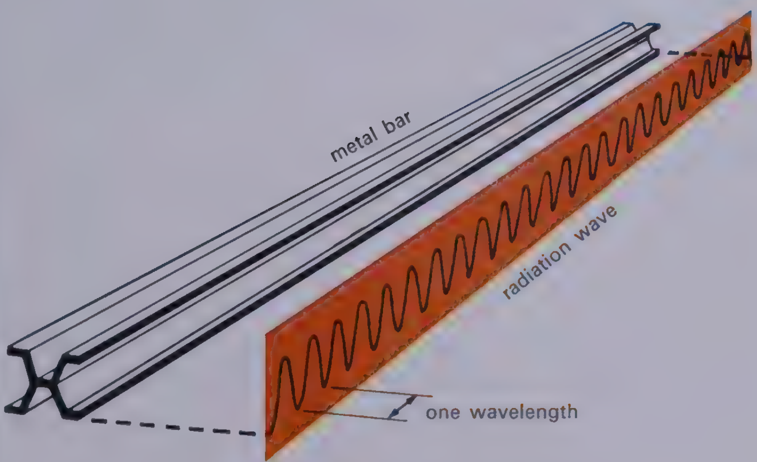


Figure 7 • 6.
The standard meter was originally a metal bar, *shown at left.* The meter has since been defined in terms of wavelengths of a certain kind of radiation.

2. Most of the non-English-speaking nations have adopted the metric system. England has changed to the metric system, but the United States still uses the English system. Do you think we should change our standards of measure? Give reasons why we should or should not change.

ON YOUR OWN: Measuring the Height of a Tree

The early Egyptians developed a method to determine the height of trees used to make masts. They used a stick about 2 meters long. How could they determine the height of a tall tree with a short stick without touching the tree?

You can answer this question yourself by investigation at home or after school. Hint: you must do this on a sunny day. You will not be given further help. Can you do as well as the early Egyptians? Report your results to the class.

INVESTIGATION 7.2: Centimeters and Inches

So far you have used some parts of the metric system, such as the gram for a unit of weight and the milliliter for a unit of liquid. While this investigation may be one you have already done on your own, a review of part of the metric system may help you achieve success in future investigations.

MATERIALS (per student)

metric-English ruler, plastic (6- or 12-inch)
Paper

PROCEDURES

A. Carefully examine your ruler. Note that on one side it is calibrated in inches. The marks between inches may include ¹⁄₁₆ inch, ⅛ inch, ¼ inch, ½ inch, and ¾ inch.

B. Now examine the metric side. Note that there are only two units of measurement, millimeters and centimeters. The smaller mark is the millimeter, meaning $\frac{1}{1000}$ of a meter. The larger mark is the centimeter, meaning $\frac{1}{100}$ of a meter. There are 1000 millimeters in 1 meter.

PROBLEMS

1. How many millimeters are there in 1 centimeter?
2. How many millimeters are there in 6 centimeters?
3. How many $\frac{1}{8}$ inch units are there in 1 inch? In 6 inches?
4. Measure each of the following lines in both inches and centimeters. Record results in your notebook.

line A

line B

line C

5. Approximately how many centimeters equal 1 inch?
6. What is the total length of lines *A*, *B*, and *C* in the English system? In the metric system?
7. Which system of measurement do you find easier to use?

PROBLEMS

(pages 152–154)

1. Students should recognize that by using the same system of measurement, scientists throughout the world are able to exchange certain kinds of information regardless of language barriers. This question could be expanded to include a discussion of communication problems among peoples of different nations.
2. Some reasons students may give:
   a. If the United States changed from the English to the metric system, the change would cause (temporarily, at least) great inconvenience in day-to-day calculations and transactions and in the design, planning, and production of almost any item that comes to mind. For example, you might ask several students to look into the problems that would arise in converting a blueprint, a relief map, or a floor plan from the English to the metric system.
   b. If the United States changed, there would be greater opportunity and therefore less difficulty in learning and using the metric system.
   c. If the United States changed, there would be better international and eventually better domestic communication.

ON YOUR OWN: Measuring the Height of a Tree

(page 154)

Some students may find this investigation difficult, and weather conditions may interfere. If so, it can be postponed. It may be performed at any time of the year without disrupting the course.

When the upright stick's shadow is equal to the length of the stick, the length of the tree's shadow will be equal to the height of the tree. (This is probably the most obvious method, but it involves a delay since the student must wait until the sun is in exactly the right position. This varies from day to day.) The delay can be avoided by using simple proportions:

$$\frac{\text{length of stick}}{\text{length of stick's shadow}} = \frac{\text{height of tree}}{\text{length of tree's shadow}}$$

or

$$\text{height of tree} = \frac{\text{length of stick} \times \text{length of tree's shadow}}{\text{length of stick's shadow}}$$

(Thus, the tree can be measured at almost any time on a sunny day.)

INVESTIGATION 7.2: Centimeters and Inches

(pages 154–155)

This brief introduction to linear measurement in both the English and metric systems is designed to help those students who may be somewhat intimidated by the metric system. It is not our intent to have students memorize English-metric conversion tables. This information is included in Appendix C.

MATERIALS

Use inexpensive plastic rulers. The ones used in Section Three may be used for this investigation.

PROCEDURES

A. Some students may need help in reading the English side of the ruler since fractions are involved.

B. Help students if necessary, but allow them to discover for themselves the relationship between millimeters, centimeters, and the meter.

PROBLEMS

1. Simply by counting the number of small marks on the ruler, students should discover that there are 10 millimeters in 1 centimeter.
2. If students solve Problem 1, they should have little difficulty in solving this problem. If there are 10 mm in 1 cm, then there must be 60 mm in 6 cm ($6 \times 10 = 60$).

3. Some students may have difficulty in solving this problem because of the fractions involved. However, most students should realize that there must be eight $\frac{1}{8}$ inches in 1 inch ($\frac{1}{8} \times 8 = \frac{8}{8} = 1$ inch). In 6 inches there must be forty-eight $\frac{1}{8}$ inches ($8 \times 6 = 48$; $48 \times \frac{1}{8} = \frac{48}{8} = 6$ inches).

4.

	English	*Metric*
line A	$= 3\frac{15}{16}$ inches	100 mm, or 10 cm
line B	$=$ about $2\frac{9}{16}$ inches	65 mm, or 6.5 cm
line C	$= 1$ inch	25 or 26 mm, or about 2.5 or 2.6 cm

5. Most students will probably say that 2.6 cm = 1 inch. The actual value is 2.54 cm = 1 inch. Explain that the smallest unit in nearly all metric rulers is 1 mm. Therefore, one must estimate the distance between mm marks. As a general rule of thumb, one can consider that 2.5 cm approximately = 1 inch.

6. This problem may be the most difficult for many students. To illustrate one major difference between the English and metric systems, divide the class into two sections. Have one section solve the problem in the English system and the other in the metric system. Ask students in each section to raise their hands when they have solved the problem.

   Students may enjoy this comparison of the two systems as a game. The rules should be that the metric team gives the answer in cm and the English team gives the answer in a reduced fraction form. The team that solves the problem first would win the contest.

   The solution in inches would be:

$$3\frac{15}{16} + 2\frac{9}{16} + 1 = 6\frac{24}{16} = 6\frac{3}{2} = 7\frac{1}{2} \text{ inches}$$

   The solution in centimeters would be:

$$100 + 65 + 26 = 191 \text{ mm} = 19.1 \text{ cm}$$

7. Student answers may vary. We anticipate that they will find the metric system easier to use. This may depend on the math background of your students.

INVESTIGATION 7.3: Measurement of Length, Width, and Area

This investigation will give you an opportunity to experience some of the difficulties in measuring that might have confronted a student living during the eighteenth century. It will also allow you to use some modern methods of measurement.

MATERIALS (per team)

Cubit stick
Yardstick
Meterstick

PROCEDURES

A. Using your cubit stick, measure the length and width of a desk or table. Record your data.
B. Find the area of the same desk or table in square cubits.
C. Find the area of the same desk or table in square inches, using a yardstick. Using a meterstick, find the area of the same desk or table in square centimeters.

INTERPRETATIONS

1. What are the advantages and disadvantages of using your own units of body measurement (cubit, span, and so forth) in reporting measurements?
2. Which system of units did you find most useful? Which is most precise?
3. What is meant by the statement, "All measurements are only estimates"?

ON YOUR OWN: Inventing a Measuring Device

So far you have used both the English and metric systems of measurement in several investigations. You have also constructed and used a cubit stick—an ancient type of measuring device.

In this investigation, you are asked to invent still another means of making linear measurement. The only restriction is that you *do not* use a ruler, in any way, to help you invent a different kind of measuring device. Your work should be done after school or at home.

There are many possible devices or systems that you could invent. Here again is an opportunity for you to use your own imagination and skill.

You might begin by imagining that you lived in ancient times and that no system of measurement existed. But you wanted to construct a building and had to have some means of measuring the length of lumber in order to construct your building. What would you do? Feel free to use any kind of easily available material and to use any kind of words to describe your units of measurement. For example, suppose that your smallest unit is called a *glub*. Then 10 glubs could be a *soot* and 100 glubs a *pard*. Please do not use these words. Invent your own!

You could use body measurement other than cubit, span, palm, or digit. But there are many other possibilities. It is up to *you*.

INVESTIGATION 7.3: Measurement of Length, Width, and Area

(page 156)

In this investigation students should find great variation in data obtained by measuring with the cubit stick. Students will also gain practice in using English and metric rulers to determine lengths and areas. Throughout the course both the English and metric systems of measurement are used. The English system is more convenient for those students who experience difficulty in learning a new "language" of measurement. However, since the metric system is more often used in scientific work, students should be encouraged to use metric units.

We hope that the next few investigations will help students understand the *meaning* of density regardless of the measurement system used.

PROCEDURES

A. A sufficient number of students should measure the same object, using the same units of measure to permit a comparison of results. You might ask a student to make a chart on the chalkboard, where individual results can be recorded and compared.

B. Students may need to be reminded that area = length × width.

C. No comment.

INTERPRETATIONS

1. Units of body measure are convenient to use, but they vary from person to person.
2. Answers to this question may vary. Some students will favor the English system, others the metric. When students find it necessary to do calculations from measurements, they may find the metric system more convenient, because it is based on the decimal system.

   It is not possible to say that the English or the metric system is more precise. A ruler divided into sixty-fourths of an inch yields more precise values than a ruler with centimeters as the smallest subdivision. On the other hand, a ruler marked in millimeters gives better results than one marked only to the nearest eighth of an inch.
3. If we try to measure anything precisely, we are likely to find that repeated measurements of the same object do not yield identical data. We have difficulty reading a measurement more precisely than the finest gradation marked on a ruler, graduated cylinder, or balance. Thus we are always *estimating* to the degree that we must make such judgments.

You may find the following discussion helpful in leading students to a better understanding of variability in measurements and to the concept of *experimental error*.

The investigator recognizes the inevitability of error, even in the most honest and careful work with measurements. Students who understand this will be less open to frustration and discouragement. "An Invitation to Enquiry," beginning below, explores several kinds of experimental error. If you use the Invitation, some notes on techniques may be helpful:

The teacher presents a problem, phenomenon, or set of data that requires interpretation. The teacher then asks all students to participate in the discussion. The teacher can keep the discussion going by recognizing the proper time to supply more information, ask suitable questions, and keep the discussion orderly.

Teachers who are inexperienced in this kind of class discussion often find it difficult to keep from "telling the whole story." The object here is to encourage each student to formulate his own questions and hypotheses concerning a given problem, to design experiments that may yield data useful in testing the hypothesis, to evaluate data in terms of the hypothesis, and so forth. It takes considerable skill to guide the class, by questioning, toward logical and satisfactory conclusions. You should be able to use the same technique in presenting other concepts to your students.

Carefully read through the Invitation before presenting it to your class. You may want to put the data chart for this Invitation on the chalkboard or overhead projector so it can be referred to easily during class discussion.

The material in brackets is intended for the teacher. It will help you lay the proper groundwork and suggest some answers that are likely to be given by students.

AN INVITATION TO ENQUIRY[T1]

(SUBJECT: *Measurement in general*)
(TOPIC: *Systematic and random error*)

[1. Experimental error is inevitable; it can be reduced, not eliminated.
2. Since error is inevitable, data are practically always equivocal. That is, the defensible interpretation is almost always "cleaner" than the data,

[T1] Adapted from *BSCS Biology Teacher's Handbook* (1st ed.) [John Wiley & Sons, 1963] Invitation 5, pp. 64–67. By permission of the Biological Sciences Curriculum Study. Teachers of *Interaction of Matter and Energy* may find a number of Invitations in this handbook useful.

for what we are reluctant to include in our interpretation we can often ascribe to experimental error.

3. One man's "experimental error" may be the food of the next man's research. That is, the variation in the data may *not* have been due entirely to experimental error. The variation may indicate a factor overlooked in the design of the experiment.]

To the student: (a) Over a period of a week, four students made five measurements each of a metal bar which was kept in their laboratory. They were given the impression that each was measuring a different bar each time. The record of their measurements (in millimeters) is as follows:

Measurement	*Student 1*	*Student 2*	*Student 3*	*Student 4*
1	500.0	500.0	499.8	500.1
2	499.9	500.0	499.9	500.1
3	500.0	500.0	500.1	500.2
4	500.1	500.0	500.2	500.3
5	500.2	500.0	500.2	500.3

Notice the difference between the measurements reported by student 2 and those reported by students 1, 3, and 4. How would you describe the difference? What do you think explains it?

[The difference between the report of student 2 and the others lies in the uniformity of student 2's measurements. Some of your students—those least experienced in the laboratory—may explain this as due to the greater accuracy of student 2. The more sophisticated of your students may suggest the contrary—that student 2 let his first measurement influence his reading of later measurements, or even that he is cheating in an extremely silly way. You can then appeal to their own experience to indicate that the first interpretation is the *less* likely of the two, that uniformity is *not* characteristic of actual measurements and is always suspect. This point should end by introducing the term "experimental error," meaning unavoidable inaccuracy and inconsistency of measurement.]

To the student: (b) Now compare the measurements reported by student 4 with the other reports. What overall difference is there? How would you explain this difference? *Hint:* Think of the measurement you would obtain if you read the right end of the measuring stick while standing at its left end, with the stick on top of the measured bar. Then think of what the measurements might seem if you stood in line with the right end of the measuring stick.

[Student 4's measurements are uniformly higher than most. The hint is intended to lead the student to see that conditions of measurement may vary from one investigator to another, and thus lead to different data. You may wish to have these variations actually experienced. If so, obtain a measuring

stick and have one student stand well to the left, another well to the right, while each estimates some measurement.

[If you feel your class is ready for it, you can drive the idea of experimental error home by clarifying the difference between *random* error and *systematic* error. Student 4 represents a case of systematic error. The entire group of measurements, irrespective of the students making each measurement, would come close to exemplifying random error. The most important reason for making the distinction between random error and systematic error is that our common ways of making use of numerous measurements (by calculating their arithmetic mean, their mode, or their median, for example) are ways of correcting *random* error. We have no readily available way of detecting or correcting systematic error except by watching our habits. Hence, systematic error is potentially a source of danger, whereas a reasonable amount of random error is not.]

To the student: (c) Suppose a later experiment required an estimate of the length of the bar to be used in *many* arithmetic calculations. In that case, what estimate would you choose as being "good" enough and also convenient?

If the future experiment required the *best* estimate from these data of the length of the bar, what number would you choose to use, and how would you go about calculating it?

[The two questions are put together so that the students will have a chance to contrast the idea of a "convenient" measure with the idea of a "best" measure. The most convenient measure would, of course, be 500.0. The "best" estimate, making no further allowances for differences between early and later measurements and measurements done by different students, would be a simple arithmetic mean, an average. This is computed, of course, by summing all the measures and dividing by the number of measurements.]

To the student: (d) What could we do to make this "best" estimate even more reliable?

[The answer, of course, is to secure more measurements.]

To the student: (e) There are two ways to secure additional measurements. One would be to have the same students do the job. Another would be to call on additional students to contribute. What kind of error, systematic or random, would be reduced more by the second method than by the first?

[Method 2 would reduce the overall systematic error more than would method 1 if you are lucky or wise in your selection of students.

[Thus far we have treated the problem of measurement only from the viewpoint of error introduced by the investigator. In the remaining portion of the Invitation we deal with error introduced by unnoticed changes in the thing being measured. This is, of course, one of the kinds of problems to be met in controlling an experiment.]

To the student: (f) Now inspect each column of measurements from the top down. What *trend* is noticeable? What—besides a new sort of systematic

error—might explain this trend? *Hint:* Remember that the measurements were made over a period of a week. Remember, too, that the bar being measured was made of metal, and that metals are subject to changes due to environmental factors.

[There is a clearly noticeable trend (ignoring student 2) toward larger measurements on the later days. The second hint is intended to turn the student's attention to the possibility that the bar actually became longer as the days grew warmer. You will probably need to guide the students into seeing and understanding this possibility.

[In actuality, no readily available metal has a coefficient of expansion as great as is indicated by our fictitious measurements.]

To the student: (g) Suppose that the trend just discussed had been overlooked or treated as experimental error. Further, suppose that the measurements were used to support a certain theory according to which the rod ought to be nearer 500.1 mm long than to 500.0. Unless this experiment were repeated by others at different times and places, what might happen to the field of study that defended this theory?

[It might well have adopted the theory in question. Then, only when later inconsistencies appeared would the theory have been called into question. Only then might the experiment have been repeated by someone and the error discovered.

[This exemplifies the point made in the introduction to this Invitation—what one man ascribes to experimental error may be the basis, through research, of other and more useful investigations.]

To the student: (h) In view of your answers to *(e)* and *(g)* explain what is meant by saying that science is a *social* enterprise.

[The idea here is that for some problems many heads are better than one; that science depends on debates and differences, on alternative approaches to problems.

[By now, your students are, we hope, on the way to regarding data as only approximations of what is, and to seeing that what is is ever elusive, although we may refine our attempts to define it more accurately.]

ON YOUR OWN: Inventing a Measuring Device

(pages 156–157)

This investigation provides another opportunity for individualized study. However, two or more students may wish to work together in inventing a measuring device. Whether or not this option should be allowed is up to the teacher.

We cannot predict what system of measurement students may develop. There are a number of possibilities that might be included.

1. Folding a long string in half, then each half into quarters, etc.
2. Constructing a "cubit stick" equal to a person's height and using different names for the measurement units.
3. Linking together a large number of paper clips to form a chain. Each paper clip could represent a unit of measure—a clip.
4. Folding a long piece of adding machine tape into halves, quarters, etc.

Students can be quite ingenious in devising new methods.

Some students may wish to construct a box or some other object, using their measuring devices. However, it is not recommended that you ask them to do this as a class assignment. You might mention such a project for those who would like to use their measuring device for construction purposes.

INVESTIGATION 7.4: Determining the Volume of Solids

The space that an object or a substance occupies is called its *volume*. It is relatively easy to determine the volume of liquids by using a graduated cylinder. Determining the volume of a solid requires different techniques. Recall that you found the area of a desk top or tabletop by multiplying the length by the width. You determined the area in square cubits, square spans, square feet, square centimeters, and so forth. To determine the volume of a door or other rectangular object, you must multiply the area of the object by its depth. For practice, suppose you wish to find the volume of the rectangular object shown in Figure 7 • 7.

Figure 7 • 7.

The area of one of the rectangular sides is 4 inches x 2 inches, or 8 square inches. The volume is 8 square inches x 2 inches, or 16 *cubic* inches. Thus the dimensions involved are length, width, area, and volume. *Cubic* should not be a new term for you (sugar cubes, ice cubes). Cubic measurement is necessary in determining the volume of solids.

MATERIALS (per team)

Rectangular solids of different sizes, 2
Ruler calibrated in inches and centimeters
Graduated cylinder, 50- or 100-ml
Overflow can

Yard of thread
Graph paper
Nails, marbles, and other objects small enough to fit in graduated cylinder
Straight pin or fine wire
Small pieces of wood (irregular shapes)
Sugar cubes

PROCEDURES

A. In your notebook, copy the chart shown in Figure 7 • 8.

B. Number the solids. Use your ruler to determine the volume of each solid in cubic inches and in cubic centimeters. Record this data on your chart.

	Trial Number	*Solids* 1	2
Volume in cubic inches	1		
	2		
	3		
	average		
Volume in cubic centimeters	1		
	2		
	3		
	average		
Volume of displaced water in milliliters	1		
	2		
	3		
	average		

Figure 7 • 8.

C. Place the graduated cylinder under the spout of the overflow can. Fill the can with tap water until water begins to flow from the spout. When the flow has stopped, empty the graduated cylinder and place it under the spout again.

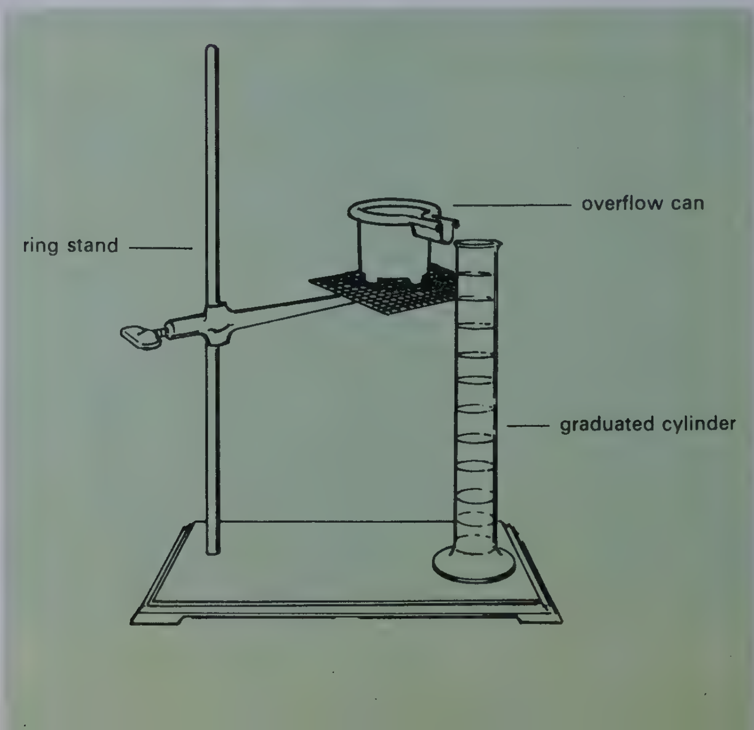
D. Tie a thread around Solid I and lower it carefully into the water. If the solid does not sink, hold it underwater with a pin or small probe.

E. Keep the solid completely submerged until the water has stopped flowing into the cylinder. Then carefully measure the amount of water in the cylinder.

Recall from Section Two that water has a slightly concave surface when confined in a narrow cylinder. This could cause some error in determining volume. The accepted scientific practice is to take the reading at the lowest point of the curve (Figure 7 • 10). It is also important that the cylinder be on a level surface. The reading should be taken at eye level.

Repeat Procedures D through E two more times. Record on your chart the volumes for each of the three trials with Solid I. Calculate the average volume obtained with each method.

Figure 7 • 9. Setup for Procedures C–F.



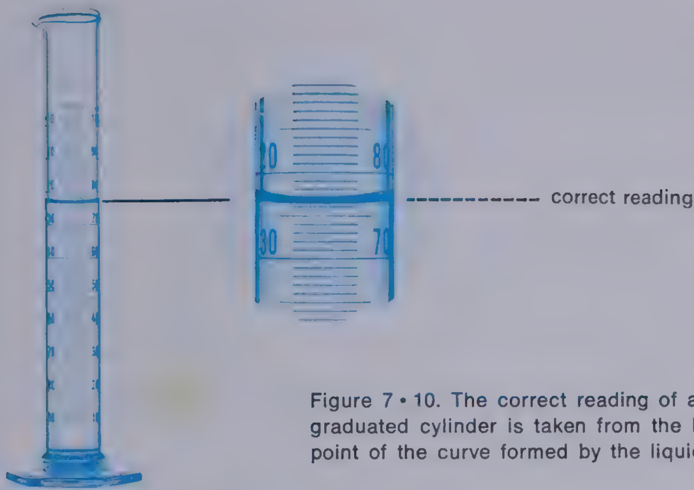


Figure 7 • 10. The correct reading of a graduated cylinder is taken from the lowest point of the curve formed by the liquid.

F. Repeat Procedures B through E for Solid II. Be sure to record the data for each of the three trials with each solid.

G. On graph paper, construct the graph shown in Figure 7 • 11. Use the vertical axis of the graph for volumes in cubic inches and the horizontal axis for the number of milliliters of water displaced (collected in the graduated cylinder). Plot the *average* of the three trials for each solid. Beginning at zero, draw a line connecting the three average points.

Figure 7 • 11.

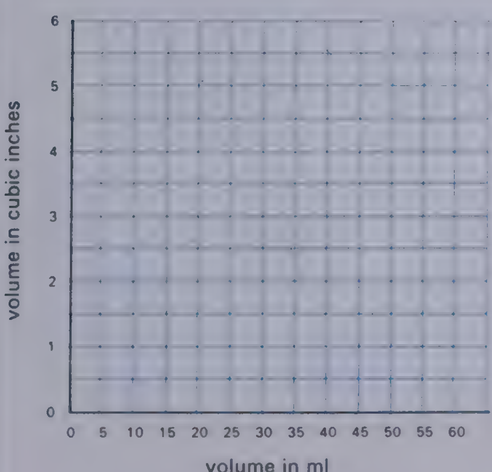
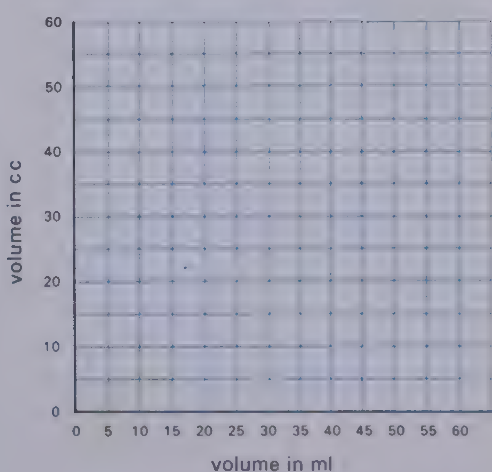


Figure 7 • 12.



H. Using another piece of graph paper, repeat Procedure G, but plot the values for volume in cubic centimeters against volume of displaced water in milliliters (Figure 7 • 12).

INTERPRETATIONS

1. Note the relationship between the volumes in cubic inches, cubic centimeters, and milliliters. Which system—English or metric—seems to be the easiest to use in finding the volume of a solid?
2. Carefully compare the two graphs and describe any differences or similarities.
3. In Procedure G, were you able to draw a straight line from zero through the two average points? If not, how can you explain the results?

PROCEDURES

I. You may wish to determine the volumes of other objects. The overflow can is not needed for objects small enough to be placed directly in the graduated cylinder. Pour enough water into the graduated cylinder to completely submerge the object. (Usually this can be done if the cylinder is about half full.) Read and record the volume of the water. Submerge the object in the water and again take a reading from the cylinder. If the object floats, hold it under the water with a pin or fine wire. What is the volume of the object?

PROBLEMS

1. Use a ruler (English and metric) and the water-displacement method to measure the volume of each of the following:
   a. an irregularly shaped piece of wood
   b. a cube of sugar
2. Which method of measuring volume did you find most useful in Problem 1? Which system—English or metric—did you find most convenient?

ON YOUR OWN: How Much Overflow?

You have learned how solids immersed in water displace a certain amount of water, and you probably already know that water expands in volume when it changes to ice.

In this investigation, place about two large cubes of ice in a glass jar or drinking glass. Add water until the water level is even with the top of the glass.

Predict what the water level will be after the ice melts. Then observe what happens as the ice melts and record the results in your notebook. Try to explain the results you observed.

NOTE: *A slight amount of water from the air may condense on the outside of your glass. Disregard this and concentrate on the change in water level as the solid ice cubes melt.*

Was your prediction correct? Be prepared to explain the results of this investigation to the class.

INVESTIGATION 7.4: Determining the Volume of Solids

(pages 158–162)

Students may feel that the explanation for determining the volume of a rectangular solid is too elementary. Emphasize that this explanation is used only as a review. Those students who do not recall this part of their training in arithmetic may need to "rediscover" the mechanics of multiplying three values to obtain the volume of a rectangular solid. We recommend that you do not carry the arithmetic drill further than is necessary for the investigation.

MATERIALS

Artgum erasers are ideal for this investigation. They are relatively true rectangles and can be obtained easily and inexpensively in various sizes. Plastic, wood, or metal blocks can be used if available.

If enough graduated cylinders are not available, teams can share cylinders, or the size of teams can be increased.

Use inexpensive plastic rulers calibrated in both metric and English units.

Overflow cans can be obtained from most scientific supply houses or can be constructed fairly easily. A small teapot is a good substitute.

Standard linear graph paper will be adequate. Because the centimeter is a smaller unit than the inch, the two graphs (Figures 7 • 11 and 7 • 12) will have to be adjusted accordingly.

PROCEDURES

A. No comment.

B. Students may have trouble multiplying fractions when using the English system. They should have less difficulty with the metric system, because it is based on the decimal system.

C. Be sure that no water is left in the bottom of the graduated cylinder.

D. If a large probe is used to hold the object underwater, the volume of the submerged part of the probe will add to error in the determined volume of the object.

E. Data from several trials will help reveal experimental errors.

F. The second and third solids will provide additional data for comparison. If different objects are used, students are less likely to "invent" measurements to insure uniformity.

G.–H. Make sure students use the vertical axis for the measured volume of the solid and the horizontal axis for the number of milliliters of water collected.

INTERPRETATIONS

1. Students should note that the measured volume in cubic centimeters is numerically almost equal to the volume in milliliters of displaced water. They should also note that a 1:1 ratio does not exist between the volume in cubic inches and the volume in milliliters.

   Neither system should be judged better than the other, and students' answers will vary. Some students may find it more convenient to use the metric system.
2. The lines will slope differently in the two graphs. The metric-data graph should indicate a 1:1 relationship between the volume of a solid in cubic centimeters and the volume of water in milliliters. The other graph should show a relationship close to 1 cubic inch:15 ml. See Figures T-7 • 1 and T-7 • 2.

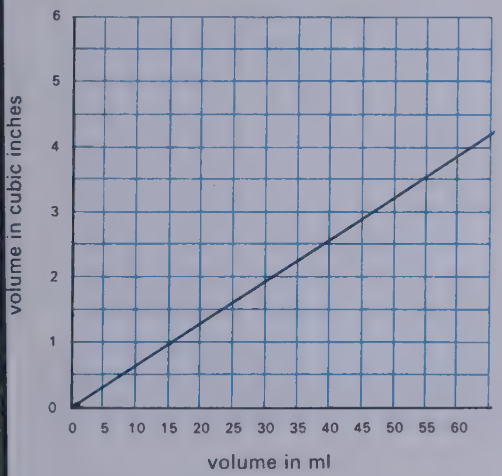


Figure T-7 • 1. Graph showing a 1:15 ratio.

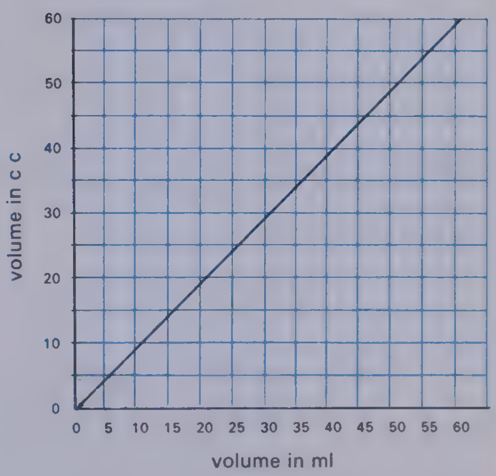


Figure T-7 • 2. Graph showing a 1:1 ratio.

3. Because of experimental error, it is unlikely that all three points will occur in a straight line.

PROCEDURES

I. Use marbles, nails, or other objects small enough to go into the graduated cylinder. For objects having small volume, such as small nails or paper clips, use several identical objects to gain an observable change in the reading. Then divide this result by the number of objects immersed.

PROBLEMS

1. This activity should demonstrate two things:
   a. It is difficult to measure the volume of an irregular solid with a ruler but easy to do so by measuring the volume of water displaced by the solid.
   b. Solids that are regular in shape can be conveniently measured with a ruler. If such solids are soluble in water, the displacement method may yield poor results. In this case it may be possible to find a liquid in which the solid is not soluble.
2. It is probably easier to measure the dimensions of a regularly shaped solid with a ruler and calculate its volume than to use the water-displacement method. If the object is small enough to go into the graduated cylinder, students may prefer the displacement method because it does not require calculations of volume by multiplication. The displacement method is clearly preferable for measuring the volume of objects with irregular shape.

ON YOUR OWN: How Much Overflow?

(page 163)

This is a relatively easy "On Your Own" investigation. Many students may correctly predict the outcome.

Actually the water level should not change as the ice melts. When water freezes, it expands. An ordinary ice cube has a volume of about 1.1 times the volume of the water used to make the ice cube. As the ice melts, it loses this extra volume, becomes water again, and no change in water level occurs.

INQUIRY DEMONSTRATION: Increasing Density *(Optional)*

(Teacher Only)

This demonstration requires about five days to complete. It may be conducted while students perform Investigations 7.5 and 7.6. At regular intervals students will observe a beaker containing a clear liquid. The liquid will *appear* to be water, and its density will be approxi-

mately 1 g/ml. Each day, however, a determination of mass-to-volume relationship will reveal that the density of the liquid has increased.

MATERIALS

Tap water, 50 ml
Bunsen burner
Table sugar, 25 g
Ditto fluid (methyl alcohol), 50 ml
Beaker or jar, 150 ml
Graduated cylinder of known weight, 100 ml
Balance sensitive to 0.1 g

PROCEDURES

A. Bring 50 ml of water to a boil, add sugar, and stir the mixture. Allow the solution to cool until it is warm to the touch and add Ditto fluid (methyl alcohol). The solution should be cool enough so that evidence of preheating will not be apparent to students. Pour the solution into a beaker just before the students come to class.

B. Ask students how they might identify the clear solution without touching, tasting, or smelling it. Honor all suggestions, but avoid trying chemical tests. Accept a tentative conclusion that the liquid is water and guide students into suggesting that the relationship of mass to volume be determined.

C. Determine the density of the solution and record it on a large chart similar to Figure T-7 • 3. *Do not allow students to touch the beaker.* The density will be very close to 1 g/ml.

Day	*Mass of Cylinder*	*Mass of Cylinder and Solution*	*Mass of Solution*	*Volume of Solution*	$\frac{\textit{Mass}}{\textit{Volume}}$
1					
2					
3					
4					
5					

Figure T-7 • 3.

D. On each succeeding day allow a few minutes for students to remeasure the volume and weight of the solution. Have students calculate the relationship, and add this data to the chart. Ask them to explain the changing relationship. Honor all suggestions, but do not reveal an answer until Investigation 7.6 has been completed.

EXPLANATION

A solution of sugar and water is denser than water, while a solution of alcohol and water is less dense. When warm water is used, the density of the water-sugar-alcohol solution is nearly that of water. Depending on humidity and air currents, the density should increase steadily as the solution of alcohol and water evaporates.

Students are not likely to suspect that the increasing concentration of dissolved material (sugar) is responsible for the increase in density, until enough evaporation has occurred for crystals to appear.

It is important that students complete Investigations 7.5 and 7.6 before a final summary of this demonstration is made. In those investigations they will become acquainted with weight/volume relationships for several substances.

Upon completion of the calculations and investigations on density (Investigation 7.7), your students should be able to produce a graph which shows the daily changes in the density of this solution. From the graph they can calculate both the weight and volume of the material which leaves the system (mostly alcohol at first and later mostly water). This analysis, plus consideration of the effect of heating the original container, should help them better understand the concept of density.

INVESTIGATION 7.5: Mass and Volume of Water

Matter is described as any substance that has mass (weight) and occupies space (volume). For now we will use the words *mass* and *weight* as if they had the same meaning. Later in the course, understanding the difference between mass and weight will become important.

The relationship between mass and volume will be examined in this investigation.

MATERIALS (per team)

Balance sensitive to 0.1 g
Graduated cylinder, 50- or 100-ml
Sheet of ordinary graph paper
Colored pencil

PROCEDURES

A. Copy the chart shown in Figure 7 • 13 in your notebook.
B. Weigh the graduated cylinder and record its mass on the chart.
C. Pour some water into the cylinder. Weigh the cylinder with the water in it. Record the combined mass on the chart.

Figure 7 • 13.

Trial	*Mass of graduated cylinder in grams*	*Mass of graduated cylinder and water in grams*	*Mass of water in grams*	*Volume of water in milliliters*
1				
2				
3				
4				
5				
Average				

D. Determine the mass of the water by subtracting the mass of the cylinder from the mass of the water and the cylinder.

E. Determine the volume of water in the cylinder. Remember to keep the cylinder level and to take readings at the low point of the *meniscus* (the curve of the water's surface). Record the volume on the chart.

F. Repeat Procedures C, D, and E four more times, using a different volume of water in each trial. Record the data on the chart.

G. Plot values for the mass and volume of water in each trial on ordinary graph paper. Use the vertical axis for mass and the horizontal axis for volume. This will give you five points on the graph. Beginning at zero, draw a line connecting these points. Calculate the average mass and the average volume of water. Using a colored pencil, plot this point on the graph. Beginning at zero, draw a straight red line through the average point; extend this line as far as possible beyond the average point. Keep the graph in your notebook.

INTERPRETATIONS

1. Divide the *average* mass of water obtained in all trials by the *average* volume for all trials: $\frac{M}{V} = ?$ Compare the average value for $\frac{M}{V}$ obtained by your team with the average values obtained by other teams.
2. What relationship appears to exist between the mass of water in grams and its volume in milliliters?

INVESTIGATION 7.5: Mass and Volume of Water

(pages 164–165)

Should students question the use of the term *mass* instead of *weight*, assure them that for the purposes of this investigation the two terms have related meanings and are often used interchangeably. The concept of mass will be developed in a later section, when the distinction between mass and weight is significant.

MATERIALS

Each team should have a balance. If this is not possible, one balance can be used for the entire class. This will require that one member of each team use the balance and report his findings to the others.

One graduated cylinder per team is required. If it is impossible to obtain enough cylinders, large test tubes or similar glass containers can be calibrated and used with a reasonable degree of accuracy.

PROCEDURES

If some teams fail to allow for the meniscus (see Figure 7 • 10) and thus obtain higher readings for volume, a comparison of results may show significant variation. The teacher then has a good opportunity to stress the problem of variation in measurement that normally occurs when several individuals attempt to measure the same quantity.

A.–F. No comment.

G. The points may not all fall along a straight line, because of experimental error. Students may need help in deciding just where to draw the line so that as many points lie above the line as below it.

INTERPRETATIONS

1. The average mass for each trial divided by the average volume for each trial should give a value close to 1. $\frac{M}{V} = 1$.
2. Students are likely to arrive at approximately a 1-to-1 relationship between mass and volume of water when this value is expressed in grams per milliliter. Students should observe the close correlation between the mass and volume of the same amount of water.

   Depending on the care taken by each team, the $\frac{M}{V}$ values for water should be relatively close to 1. Any extreme variation should be discussed—not necessarily because the value at variance is

"wrong" but rather to stress the idea of experimental error (as indicated in "An Invitation to Enquiry").

NOTE: *The students' graphs should be saved until Investigation 7.6. See graph on page 167B for the slope of the* $\frac{M}{V}$ *line for water.*

INVESTIGATION 7.6: Mass and Volume of Liquids Other than Water

This investigation is similar to Investigation 7.5. With this in mind, predict what a graph developed as in Investigation 7.5 will show when liquids other than water are used.

MATERIALS (per team of four)

Balance sensitive to 0.1 g
Graduated cylinder, 50- or 100-ml
Alcohol (Ditto fluid), 50 ml
Karo syrup (white), 50 ml

PROCEDURES

Using the procedures described in Investigation 7.5, determine the mass of three different volumes of Ditto fluid. Do the same for the three volumes of white Karo syrup. Plot the three volume points for each liquid on the graph you made in Investigation 7.5. Draw a line connecting the zero point and the three points for Ditto fluid. Draw another line connecting the zero point and the points for Karo syrup.

INTERPRETATIONS

1. Examine the colored line on the graph which shows the relation of mass and volume of *water*. Select several points on the horizontal axis and determine the value of the ratio $\frac{M}{V}$ for each of these volumes. You can read the mass for each volume from the graph. Note that each point on this line represents a number you can obtain by dividing the number of grams of water by the number of milliliters of water. That is,

$$\frac{\text{number of g of water}}{\text{number of ml of water}} = \text{number of g per ml}$$

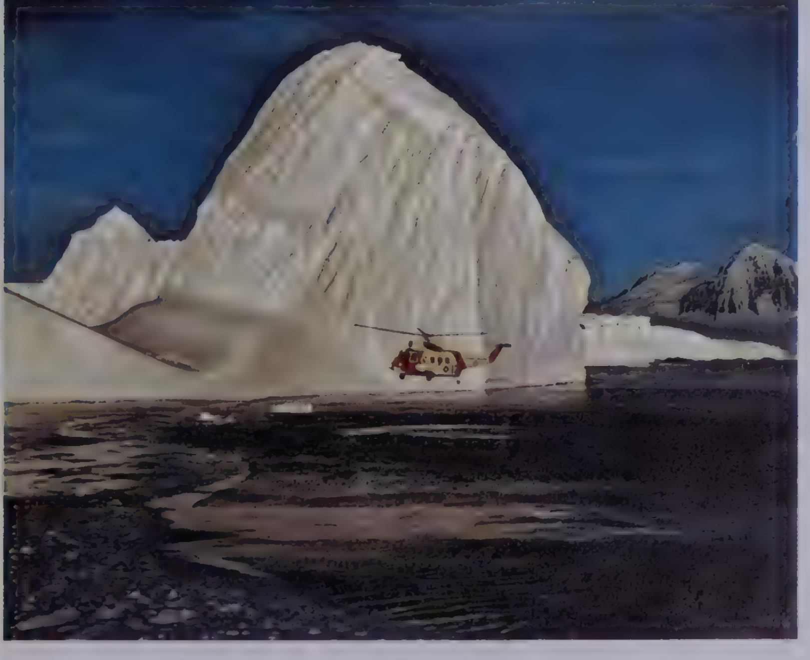
What is the value of $\frac{M}{V}$ for each of the points you have selected?

2. Determine the value of $\frac{M}{V}$ for at least three different points on the line drawn for the relationship between mass and volume of Ditto fluid. Do the same for Karo syrup.

How does the value of $\frac{M}{V}$ for Ditto fluid compare with the value of $\frac{M}{V}$ for water? How does the value of $\frac{M}{V}$ for Karo syrup compare with that for water?

The mass of material found in one unit of volume is called the *density* of the material for that volume. Here, density depends upon two kinds of units—units of mass and units of volume. Thus we can express the density of water as 1 gram per milliliter, 62.5 pounds per cubic foot, or in any other units we may choose. But we must know how many units of mass are contained in a given number of units of volume.

Figure 7 • 14. Is the density (mass to volume ratio) of the iceberg greater or less than that of the water?



INVESTIGATION 7.6: Mass and Volume of Liquids Other than Water

(pages 166–167)

From their data, students should realize that Karo syrup and alcohol have densities different from water and that the mass-volume graph for each is a straight line. These concepts will be helpful in their studies of solids.

It may be well to ask students to predict which of the three liquids —water, Ditto fluid, and Karo syrup—would weigh the most and which would weigh the least if equal volumes of each were measured.

MATERIALS

You may use any liquids available as substitutes for the Ditto fluid or Karo syrup. If possible, select one with a density lower than that of water and one with a density greater than that of water. Because its vapor is toxic, we recommend that you do *not* use mercury.

PROCEDURES

Some students may still need help plotting data on graphs. Be sure students thoroughly wash the graduated cylinder before changing liquids.

INTERPRETATIONS

1. For water (the red line on the graph), the value for $\frac{M}{V}$ is 1 g per ml.
2. The value of $\frac{M}{V}$ for Ditto fluid is approximately 0.8 g per ml; for Karo syrup it is approximately 1.3 g per ml.

   Figures T-7 • 4 and T-7 • 5 show data for a comparison of the density of water, Ditto fluid, and Karo syrup compiled by a student using a 50-ml graduated cylinder and an Ohaus Centogram balance. Note that the points in the graph do not fall precisely on a straight line. Students are likely to experience this problem, because the equipment cannot be read more accurately. This affords another opportunity to emphasize the occurrence of experimental error. We can never avoid all experimental error; we can only try to reduce it to a minimum.

Figure T-7 • 4.

Trial	Volume in M	Mass of Cylinder Plus Liquid	Mass of Cylinder	Mass of Liquid	$\frac{M}{V}$
		Tap Water			
1	12.0	72.82	59.82	13.00	1.08+
2	20.0	79.35	59.82	19.53	0.98−
3	26.5	84.91	59.82	25.01	0.95−
4	32.5	93.54	59.82	33.72	1.04−
		Ditto Fluid			
1	9.8	67.73	59.82	7.91	0.81−
2	21.0	76.07	59.82	16.25	0.77+
3	28.2	82.24	59.82	22.42	0.80−
4	33.5	86.34	59.82	26.52	0.79+
		Karo Syrup			
1	7.8	69.90	59.82	10.08	1.29+
2	14.0	77.61	59.82	17.79	1.27+
3	20.5	87.10	59.82	27.28	1.33+
4	29.3	98.15	59.82	38.33	1.31−

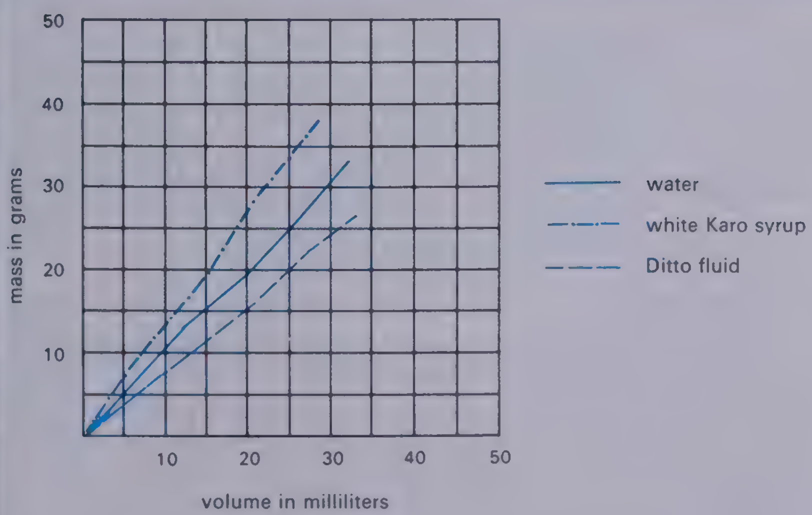


Figure T-7 • 5. Graph comparing density of water, Ditto fluid, and Karo syrup.

INVESTIGATION 7.7: Determining the Density of Various Objects *(Optional)*

In this investigation you will be given little or no instruction. If you have learned the concepts presented in the last few investigations, the investigation should not prove too difficult.

MATERIALS (per student or team)

Artgum eraser
Marbles
Small rock
Cube of cane sugar
Large nails held together with rubber bands
Small piece of Styrofoam, irregular shape
Ice cube
Graph paper

PROCEDURES

A. Determine the density $\left(\frac{M}{V}\right)$ of several of the objects listed above. Complete at least three trials with each object and record the data on a chart in your notebook.
B. Describe in your notebook each step you used in Procedure A.
C. On a graph, plot mass on the vertical axis and volume on the horizontal axis. Complete the calculations necessary to determine the density of each object.

INTERPRETATION

What do the relative densities of different substances indicate about either the number of atoms or the weight of the atoms found in the same volume of each substance?

PROBLEMS

The term *specific gravity* is sometimes used to compare the weight of a substance with the weight of an equal volume of water. By definition:

$$\text{specific gravity} = \frac{\text{weight of any volume of a substance}}{\text{weight of an equal volume of water}}$$

Since density is a measure of the weight of a given volume of a substance, we can define specific gravity in this way:

$$\text{specific gravity} = \frac{\text{density of the substance}}{\text{density of water}}$$

For example, 10 ml of mercury weighs 136 grams. We already have found that 10 ml of water weighs 10 grams. Then the specific gravity of mercury can be determined by using either of the above equations:

$$\text{specific gravity of mercury} = \frac{136 \text{ grams}}{10 \text{ grams}} = 13.6$$

or

$$\text{specific gravity of mercury} = \frac{136 \text{ grams per } 10 \text{ ml}}{10 \text{ grams per } 10 \text{ ml}} = 13.6$$

Note that the same units (grams or grams per ml) appear in both the numerator and denominator of the two fractions. When we divide anything by itself, we get 1 as the quotient. Therefore, specific gravity is a number, but a number with no units. It simply indicates how many times heavier or lighter a substance is than the weight of an equal volume of water. When we say that the specific gravity of mercury is 13.6, we mean that any amount of mercury is 13.6 times as heavy as the same volume of water.

1. If 50 ml of concentrated sulfuric acid was found to weigh 92 grams, what is the specific gravity of this substance?
2. If 1 cubic foot of seawater weighs 64 pounds, and 1 cubic foot of pure water weighs 62.4 pounds, what is the specific gravity of seawater?
3. If 1 liter (1000 ml) of gasoline weighs 670 grams, what is the specific gravity of gasoline?
4. If the specific gravity of ebony wood is 1.2, what will a cubic foot of the wood weigh (see Problem 2)?
5. The density of methyl alcohol is about 0.8 grams per milliliter. What is its specific gravity? Would 10 milliliters of methyl alcohol be heavier than or lighter than 10 milliliters of water?

ON YOUR OWN: Will Metal Float?

You have seen that different objects may have different densities. In this investigation you can study the average density, or buoyancy, of a container, with materials commonly found at home. The materials you will need are a container of water, a square of aluminum foil, and a set of weights such as paper clips or small nails.

Fold the aluminum foil into a box-shaped container with an open top. Will it float? Find out how many paper clips can be added to the box.

Then try to find answers to the following questions:

QUESTIONS

1. What happens to the water level when weights are added to the floating foil container?
2. What happens to the water level when the weights are dumped from the floating container into the water?
3. Why does the water level behave as it does in Questions 1 and 2?

Try making different shaped containers from the foil square to find out what shape will support the most weight.

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Lowenstein, Dyno. *Graphs.* New York: Watts, 1969.

INVESTIGATION 7.7: Determining the Density of Various Objects *(Optional)*

(pages 168–169)

This investigation is designed to give students complete freedom to fail or succeed as their motivation, understanding, and ability dictates. The instructor should offer a minimum of help.

MATERIALS

Several balances
Overflow water cans or the equivalent
Several graduated cylinders

The above items and an ample supply of the various objects listed on page 168 should be placed at random about the room for students to select and use as they wish. You may wish to substitute or add other objects. Some students may measure an object to obtain its volume; others may use one of the water displacement methods.

PROCEDURES

A.–C. After students determine the density of each object, they should plot results on graph paper and compare the density of each object with that of water. Results cannot be predicted, since the shapes of the objects measured are not standard. An irregular solid that is less dense than water can be made to displace its volume by holding it beneath the water with the aid of a pin. Finding the volume of the irregular piece of Styrofoam should prove challenging. Encourage students to devise their own method, before suggesting the above procedure.

INTERPRETATION

Either the number of atoms present in a given volume of a substance of high density must be greater than in the same volume of a substance of low density, or the average weight of the atoms in the first substance must be greater than in the second.

PROBLEMS

If students need help, work through this section carefully with them.

Some may not be able to understand that

$$\frac{136 \text{ grams of mercury}}{10 \text{ grams of water}} = 13.6 \times \frac{\text{grams}}{\text{grams}} = 13.6 \times 1 = 13.6$$

1. Since 50 ml of water weighs 50 g,

$$\text{specific gravity of } H_2SO_4 = \frac{92 \text{ grams}}{50 \text{ grams}} = 1.84$$

2. Specific gravity of seawater $= \dfrac{64 \text{ pounds}}{62.4 \text{ pounds}} = 1.026$
3. Specific gravity of gasoline is 0.67.
4. Since 1 cubic foot of water weighs 62.5 pounds, and ebony wood is 1.2 times as heavy as an equal volume of water, a cubic foot of the wood will weigh 75 pounds.
5. Specific gravity of methyl alcohol is 0.8. Ten ml of methyl alcohol is lighter than an equal volume of water.

ON YOUR OWN: Will Metal Float?

(page 170)

This investigation gives the student a chance to apply his knowledge of density to the problem of buoyancy.

MATERIALS

Clay can be used in place of aluminum foil for more freedom of design. The weights can be any set of similar objects. In place of paper clips or small nails, students could use marbles, small ceramic tiles, or any other object not harmed by water.

It is helpful, but not essential, that the container for water be transparent. If you want students to compete or compare results, they should be told to use the same size squares of foil and the same kind of weights.

PROCEDURES

The number of weights supported depends on the size of the foil and the kind of weights used. A square of foil 6 x 6 cm supported thirty paper clips without sinking.

QUESTIONS

1. Students should find that the water level moves up when weights are added to the floating container.
2. Students should find that the water level moves down when the weights are dumped from the floating container into the water.
3. These two observations are related to Archimedes' principle of buoyancy—that an object is buoyed up by the amount of water it displaces. In the floating container, each weight displaces a volume of water equal to its own *weight*. When submerged, each object displaces a volume of water equal to its own *volume*.

The shape with the least area of multiple thickness (folds) has the maximum volume and therefore the maximum buoyancy. For example, a shallow box supports more weights than a deep, **V**-shaped boat made from the same square of aluminum foil.

SUPPLEMENTARY MATERIALS

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FILMS

Man Is the Measure. Ford Motor Company. 25 minutes. Color. Use to extend this section. The film shows laboratory activities in which precise measurements are made by using sound, light, and electron beams. May be obtained by writing to Ford Motor Company, Film Library, 4316 Telegraph, Oakland, Calif. 94609.

The Metric System. McGraw-Hill Book Co. 13 minutes. Color. Show after completion of Investigation 7.6 for additional information on measurements of length, weight, and volume in the metric system.

FILM LOOP

A Study of Density. Interaction Film Loops, Inquiry in Physical Science. Chicago: Rand McNally & Co., 1972.

SUGGESTED ACTIVITIES FOR TESTING LABORATORY SKILLS AND TECHNIQUES

INVESTIGATION 7.3
Measure the length and width of a desk in meters, in centimeters, and in millimeters.

INVESTIGATION 7.4
Measure the volume of a solid using an overflow can and a graduated cylinder.

INVESTIGATION 7.6
Determine the density of an unknown liquid.

INVESTIGATION 7.6
Determine the density of an unknown solid.

INVESTIGATION 7.7
Observe the incorrect use of a balance and diagnose the error.

SECTION EIGHT

Analysis of Motion

SECTION EIGHT

Analysis of Motion

(pages 171–212)

Preview

In this section students are asked to use both Aristotelian and modern explanations to describe the nature of moving and falling objects. They are encouraged to question (but with respect for the logic) authoritarian statements about the nature of motion. They collect, interpret, and analyze data which are concerned with the concepts of force, time, friction, bending and stretching, gravity, and both constant and changing speeds. They investigate the "natural" condition of an object (both at rest and in motion). Measurements of speeding objects are made and interpreted in an attempt to understand speed and acceleration.

A major goal for the students, therefore, is to propose, evaluate, and modify models which account for motion and the effects of gravity and friction. Many interpretations are required. You may have to encourage students toward critical thinking and the open mind necessary to design investigations and to evaluate data as additional evidence is uncovered.

Students read and discuss the "Dialogue on Friction" that occurs between "You" and an imaginary gentleman named Faustus, in which Faustus believes in demons but his opponent does not. Many arguments are presented by the two until it becomes obvious that the demon hypothesis could be used to explain any phenomenon. The teacher material following the dialogue may help the students reject at last the demon model as a productive means to explain the behavior of matter.

Most of the investigations in this section are rather easy to assemble and will yield dependable results. Investigation 8.8, "Measuring Changing Speed," may, however, require additional effort. Several "practice runs" and additional trials may be required to collect dependable data.

This section includes several suggestions for individualized investigations both after class and at home. Elaborate homemade timing de-

vices have been produced by students working on their own (page 183). There may also be unique student designs to measure the speeds of a variety of moving objects (page 188). Mass and motion can be investigated at home (page 211) with a cart and weight system like the one shown on page 210.

LEARNING OBJECTIVES

Given the opportunity to inquire, to investigate, to interpret data, and to offer hypotheses about the activities in this section, students should be able to—

- Question authoritarian statements about the motion and nature of falling objects;
- Explain the role of force in determining the natural condition of an object;
- Devise their own mechanisms to produce uniform periods of time;
- Demonstrate and explain the role of force in the stretching or bending of objects;
- Manipulate and use various kinds of laboratory apparatus to measure speed and motion (metersticks, timer, inclined track with steel balls or marbles, force mechanism, speed track, force gauge, friction demonstration apparatus, etc.);
- Develop more than one model which could account for friction;
- Describe the role of gravity in changing the speed of falling objects;
- Calculate the change in speed during equal time intervals for a ball rolling down an inclined plane;
- Demonstrate critical thinking in the interpretation of data as they attempt to develop concepts of speed and acceleration;
- Clearly differentiate between mass and weight;
- Apply and relate the information gained in this section to everyday examples of motion (snail's pace, skater on ice, bowling, free fall parachutist, spacecraft "hook up," bullet speeds, etc.);
- Incorporate data from the investigations of this section into their developing models for matter and reevaluate these models as new evidence becomes available.

Early in this course you read about Aristotle, one of the greatest Greek philosophers and teachers. He wrote and lectured widely on astronomy, biology, physics, medicine, philosophy, and other subjects in which he was interested. Aristotle's opinions on nearly every subject were highly respected, and his writings affected European thought for hundreds of years.

Aristotle suggested that all matter is composed of only four elements—Earth, Air, Water, and Fire. According to this concept, most solids, such as soil or rocks, are composed chiefly of the element Earth. Steam is produced by combining the two elements Fire (heat) and Water. Aristotle also believed that each of the four elements has a natural position relative to the others. Earth, the heaviest, has the lowest position. Above Earth is Water, then Air, and finally the lightest, Fire. Each of these elements, if moved from its natural position, seeks to return to that position. Thus Earth falls through Air and Water. Water falls through Air. Fire rises through the other three.

Most substances were thought to be mixtures of two or more of these elements. Each substance tends to move upward or downward, depending upon the proportions of elements within the substance. If this theory seems silly, consider the following question: Why does smoke rise upward through Air? Followers of Aristotle would have said that smoke is a mixture of Fire and Air (with a little Earth and perhaps a little Water), but largely Fire. The natural place of Fire is above Earth, Water, and Air. Since there is more Fire than other elements in smoke, the desire of Fire to rise to its natural position is greater than the desire of the other elements. So smoke rises. Some of the element Earth, in the form of ashes, may break away from the smoke and follow its own desire to fall to the ground—its natural place.

It is difficult to argue against this kind of explanation (remember the demons). Evidence that contradicts the theory is just as difficult to collect as is supporting evidence. Aristotle attempted to provide a *reason* for the tendency of various substances to move

upward or downward. One of the questions he was attempting to answer is, Why do objects fall? We may laugh at his explanation. To say that a rock falls to the earth because its natural position is below that of Fire, Air, and Water seems strange to us. But we have no adequate answer to the question, even today. You may say that objects fall because of gravity. But what is gravity? Aristotle might say it is the desire of an object to seek the earth! Neither "gravity" nor "desire" gives us a real explanation.

Aristotle dealt with two kinds of motion in his writings. He considered the motion of falling bodies, the rising of water from springs, the rising of smoke in the air, and so forth, to be *natural motion.* Motion in such cases is caused by the natural tendency of each element to seek its natural position. But a rock that is thrown into the air moves upward and then horizontally; natural motion does not explain this. Therefore, he called the motion of a thrown object *forced motion.* He suggested a model to explain forced motion. According to this model, air, which is pushed aside by the moving object, rushes around behind the object and pushes it forward. Thus such moving objects continue to move only because there is a continuous push on them.

Aristotle suggested that heavy objects fall at greater speeds than do light objects. Earlier scholars had also stated that the speed of fall is proportional to weight—that is, a 10-pound object falls ten times as fast as a 1-pound object. Though a few writers state that their observations contradicted this, the hypothesis was accepted by most people until the time of Galileo.

Almost 2000 years after Aristotle, Galileo (1564–1642) studied the problem of motion. Galileo suggested that one must observe objects in motion, measure their speeds, compare their weights, and so forth, in order to understand motion. Some of the properties of motion were known before Galileo conducted his many experiments, but it was Galileo who established the formulas which accurately described the motion of objects. Galileo's insistence on careful observation and the need for experiments did much to change man's approach to problems of science. His writings had tremendous effect on scientists for the next few centuries.

The introductory material is designed to give students a feeling for the historical development of a scientific concept of motion. How far the discussion is carried is up to the individual teacher. However, the discussion should *not* be carried beyond that presented in the student text until Investigation 8.1 is completed.

INQUIRY DEMONSTRATION: Attraction between Objects

(Teacher Only)

This demonstration can generate considerable interest if care is taken in handling the equipment. Allow students to see only the outside of three closed coffee cans (Figure T-8 • 1). When you lay the center one (Can 2) on its side near one of the outside cans, students should observe what seems to be an attraction between them. And students should be given the impression that Can 2 will roll gently back and forth when it is placed on its side exactly halfway between the other two.

MATERIALS

Empty 2-lb. coffee cans with plastic lids, 3
Masking tape
Battery (penlight size), 1

Partially fill Cans 1 and 3 with different materials (marbles, rocks, sand, and so forth), until they do not move easily when bumped. Tape the battery to the inside of Can 2, as shown in Figure T-8 • 1. Fasten

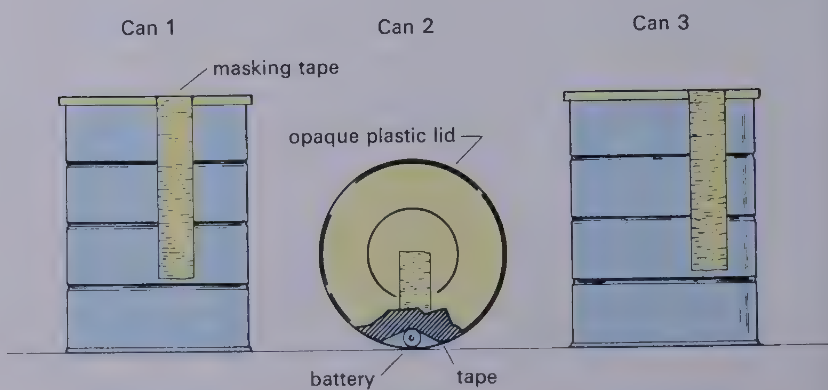


Figure T-8 • 1. Three cans prepared for Inquiry Demonstration. Cutaway view shows battery taped to inside of Can 2 in proper position.

masking tape over the lid and down the side of each can. The strip of tape on the outside of Can 2 should mark the location of the battery. (You will then be able to determine the position of the battery without opening the can.)

PROCEDURES

A. Before beginning the demonstration, describe briefly for the class the variety of ways in which things may attract one another. For example, mention the attraction of electrons for protons, magnetic attraction, chemical attraction of water and anhydrous copper sulfate, and the gravitational attraction between earth and sun.

IMPORTANT: *Practice each step in the procedures prior to the actual demonstration.*

B. Lay Can 2 on its side with the lid turned toward you (away from the class). Set Can 1 about 3 inches to the left of Can 2. Rotate Can 1 until the tape on its side faces Can 2 (Figure T-8 • 2). Turn Can 2 until the position of the battery (indicated by the masking tape) is about eleven o'clock as *you* look at it (Figure T-8 • 2). Release Can 2; it will be "attracted" to Can 1.

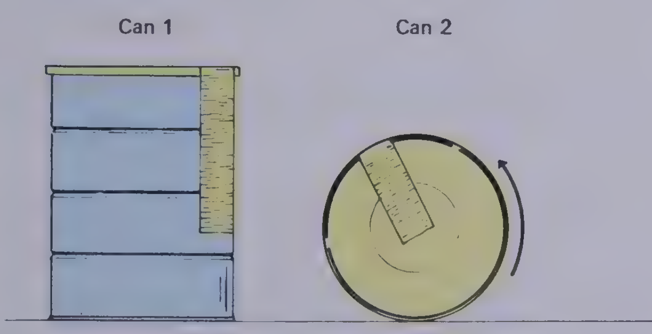
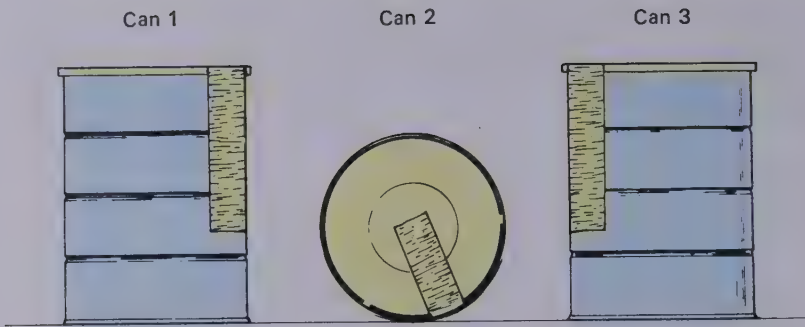


Figure T-8 • 2. Setup for Procedure B.

C. Place Can 3 about 3 inches from Can 2, with the tape facing toward Can 2. Change the position of the battery to one o'clock and release Can 2. It will be attracted to Can 3.

D. Rotate Can 3 about 180 degrees so that the tape on its side faces away from Can 2. The "negative pole" of Can 3 should seem to cause Can 2 to be repelled. As if to support this hypothesis, rotate Can 2 until the battery is at eleven o'clock and release. Stop Can 2 after it has rolled about 2 inches away from Can 3. This demonstration will appear to indicate that magnetic force is involved.

Figure T-8 • 3. Setup for Procedure E.



E. To indicate that Can 2 seems equally attracted to Cans 1 and 3, rotate Can 3 so that the tape on its side is facing toward Can 2 again. Rotate Can 2 until the battery is at a low, but off-center, position—about five o'clock or seven o'clock (Figure T-8 • 3). When the can is released, a gentle rocking action will result. This might be interpreted to mean that Cans 1 and 3 are pulling equally on Can 2.

F. Ask students to suggest what might best explain the movements of Can 2. (Most students may suggest that magnetism is responsible for the movements of Can 2. Others may say that the can rolls because of an electrical force in the "charged" cans. Some may think that gravitational attraction exists between the cans or that you pushed the cans together.)

After students are given an opportunity to offer their explanations, follow through with a test of the magnetism theory.

PROCEDURES

G. Concede that magnetism may be responsible. Place Can 2 about 3 inches from Can 3. Rotate Can 2 so it will be attracted to Can 3. Suggest that the "positive pole" of Can 3 is indicated by the tape.

H. Repeat Procedure G, using Can 1 instead of 3, and demonstrate that Can 2 is attracted to Can 1 regardless of how Can 1 is turned. This will contradict the idea of magnetic force. At this point students may be quite confused in their attempts to explain the results.

I. Rotate Can 2 so that the battery is at six o'clock. Allow students (in groups of two or three) to briefly examine the cans from all sides. *Do not permit any discussion.* After all students have examined the cans, ask them to write a short statement explaining what they observed during the demonstration. Invite each student to present his explanation to the class. Allow the discussion to continue until, in your judgment, an explanation should be given. You might wish to mention that the results were really a result of gravitational at-

traction—not between cans but between the battery in Can 2 and the earth.

This is one example of a "black box" investigation in which the investigator must explain an event without being able to directly observe all causative factors. Many experiments in science require that "black box" hypotheses be used to explain an event.

INVESTIGATION 8.1: Falling Objects

We cannot be sure just what evidence Aristotle and Galileo used to arrive at their theories about falling objects. Galileo lived about 2000 years after Aristotle, and we might expect that he benefited from some of the work done in intervening years. You will be performing this investigation about 350 years after Galileo completed his work. Later you will investigate falling objects in greater detail and take advantage of some of the ideas and equipment developed since the time of Galileo.

In this investigation you will use simple equipment to test Aristotle's theory that the rate of fall is proportional to weight—in other words, the heavier an object is, the faster it will fall. From your work, you should be able to form a judgment about Aristotle's theory.

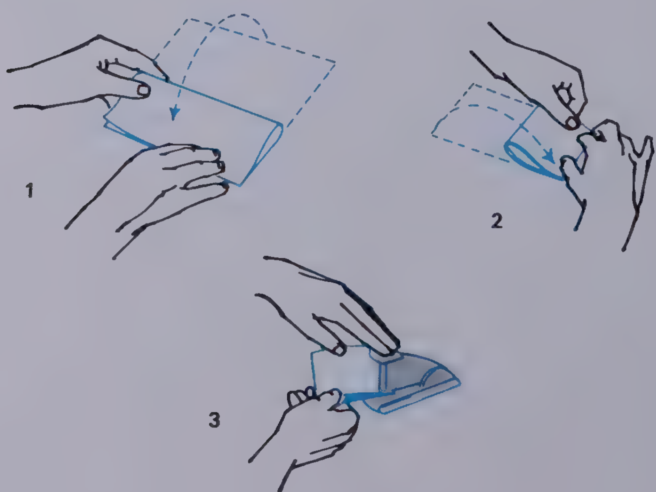
MATERIALS (per class)

Sheets of paper of uniform size
Several staplers

PROCEDURES

A. Fold a sheet of paper in half. Fold the paper in half again. Staple the four layers of paper together at the open corner (Figure 8 • 1).

Figure 8 • 1. Folding and stapling a single sheet of paper.



B. Repeat Procedure A, using two sheets of paper (Figure 8 • 2).

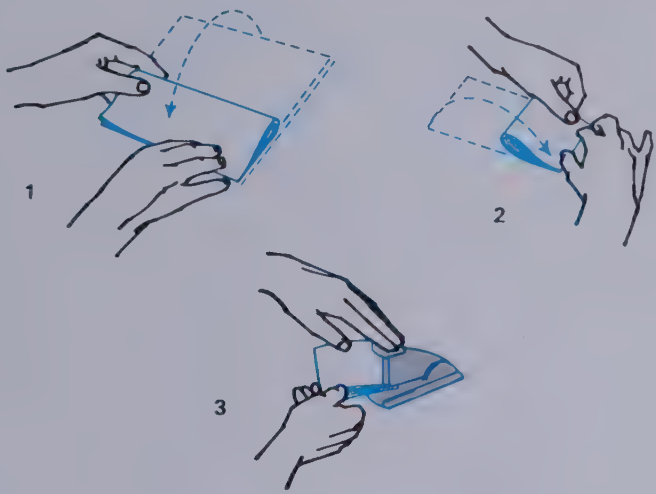


Figure 8 • 2. Folding and stapling two sheets of paper.

C. Repeat Procedure A, using four sheets of paper (Figure 8 • 3).

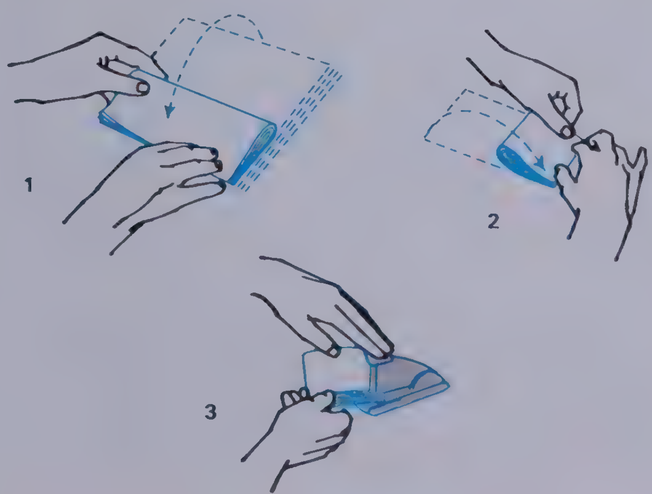


Figure 8 • 3. Folding and stapling four sheets of paper.

INTERPRETATIONS

1. According to Aristotle's theory, which of the folded papers should fall most rapidly?
2. Which of the papers do *you* think will fall most rapidly? If your answer is different from your answer to Interpretation 1, give your reason for the difference.

PROCEDURES

D. Hold the single folded sheet in one hand and the four folded sheets in the other, as shown in Figure 8 • 4. Release both at the same instant and determine the approximate difference, if any, in the time required for each to fall to the floor. Repeat several times. Record the observations in your notebook.

E. Repeat Procedure D, using two folded sheets and four folded sheets. Record your observations.

INTERPRETATIONS

3. Compare the results with the prediction you made in Interpretation 2. Make a general statement for falling objects based on your observations in this investigation.

PROCEDURES

F. To determine whether the size of an object influences its rate of fall, fold the single sheet of paper in half two more times (for a total of four folds) and staple the open side. Then compare the rates of fall of this sheet and the four sheets prepared in Procedure C.

INTERPRETATIONS

4. Does size influence the rate at which objects fall? Does weight influence the rate at which objects fall? Do light objects fall faster than heavy objects? Record your answers in the form of complete sentences.
5. Does your interpretation of Procedure F change the statement you made about rate of fall in Interpretation 3? If so, revise the statement. If not, why do you think your original explanation is still correct?

Figure 8 • 4. Carrying out Procedure D.

INVESTIGATION 8.1: Falling Objects

(pages 174–177)

Some students may have fixed ideas about the rate at which objects of different weights fall. Many may remember the story of Galileo dropping objects of different weights from the Leaning Tower of Pisa (there is no evidence that Galileo actually carried out the experiment).

NOTE: *This investigation supports the Aristotelian opinion. For the remainder of this section, students will be gathering data to support the Galilean model of gravity.*

PROCEDURES

A.–C. No comment.

INTERPRETATIONS

1. According to Aristotle's theory, the four folded sheets should fall most rapidly.
2. Students may agree with the Aristotelian view, or they may reason (incorrectly) that because of air resistance, all would fall at the same rate.

PROCEDURES

D.–E. The data recorded by students should be similar to that shown in Figure T-8 • 4.

Figure T-8 • 4.

		Comparison of Time to Fall
Procedure D	4 sheets vs 1 sheet	1 sheet was slower
Procedure E	4 sheets vs 2 sheets	2 sheets were slower

INTERPRETATIONS

3. From the results of observations made so far, the Aristotelian explanation appears to be valid.

PROCEDURES

F. Folding will reduce the air resistance for the single sheet, and it should fall at about the same rate as the four sheets.

INTERPRETATIONS

4. Both weight and size appear to influence falling objects. Light objects appear to fall more slowly than heavy objects of the same size.

5. It would appear that size is important, since one sheet folded four times falls at about the same rate as four sheets folded twice. Again encourage class discussion. Some students may modify their original explanation, others may not. Continue to try other kinds of objects. You may wish to have students crumple a single sheet of paper into a ball and compare its rate of fall with the rate of fall of the folded sheets.

At this point you may want to carry the discussion further:

When an object is allowed to fall in air, it starts accelerating as soon as it is released. As the object picks up speed, air resistance opposes gravity, and the amount of speed gained in each second declines until there is no further increase in speed. When air resistance equals the force of gravity, the object falls at a constant (maximum) speed.

There are many variables influencing the behavior of the sheets of paper. The time required for air resistance and gravity to become equal is determined by a number of factors:

a. surface area
b. shape
c. orientation with respect to air flow
d. rigidity (as it affects size and shape)
e. mass
f. distance of fall (whether either or both objects have fallen far enough to have air resistance equal the force of gravity)

Galileo thought that air resistance caused the apparently unequal rates of fall of heavy and light objects. He designed many simple experiments to illustrate his theory. He further thought that in a vacuum a heavy object would fall at the same rate as a light object. This theory was ridiculed by followers of Aristotle, partly because they didn't believe that a vacuum could possibly exist. (To this day, no one has succeeded in completely evacuating a container.)

Abouty eighty years later, Sir Isaac Newton (1642–1727) tested Galileo's theory. By Newton's time the air pump had been invented. Newton pumped most of the air out of a tall glass cylinder and showed that a heavy gold coin and a feather would fall from the top of the cylinder to the bottom in equal time. This remarkable experiment opened up an entirely new approach to the study of motion.

The preceding is offered as background information for the teacher. It would defeat the inquiry development if introduced to the class too early. The purpose of Investigation 8.1 is to introduce the study of motion and to stimulate students to rely on their senses rather than to blindly accept what has been told them.

FOR FURTHER STUDY

The following are problems and activities you may wish to present after completing Investigation 8.1 and the resulting discussion:

1. Do you think the results of Newton's experiment with the coin and the feather proved Aristotle was wrong in stating that "objects fall to the ground because it is their natural place"?

   (The experiment does not yield results that establish the "rightness" or "wrongness" of Aristotle's statement. The statement seems unacceptable to us, but we are likely to agree that objects fall because of "gravity." But "gravity" may be explained as *the tendency of two objects to come together,* i.e., seek their "natural place.")
2. Prepare a brief report on some of the ideas Aristotle, Galileo, and Newton had about motion.
3. Describe the scientific contributions of other men who lived during the times of Aristotle, Galileo, or Newton. (Refer students to Appendix B, on page 346.)

Motion and Rest

We know from experience that some kind of push is needed to make an object move. If the object is left alone, it stays at rest. It would *appear* that the natural condition of objects is rest and that motion is achieved only with a push or a pull.

INVESTIGATION 8.2: The Natural Condition of an Object

Is rest the natural condition of an object? What are some of the things that affect objects in motion and objects at rest? What kinds of measurements need to be made in a study of motion? This investigation should help you to find some answers to these questions.

MATERIALS (per team)

Grooved track and force mechanism (Figure 8 • 5)
Steel ball or marble (to fit groove)

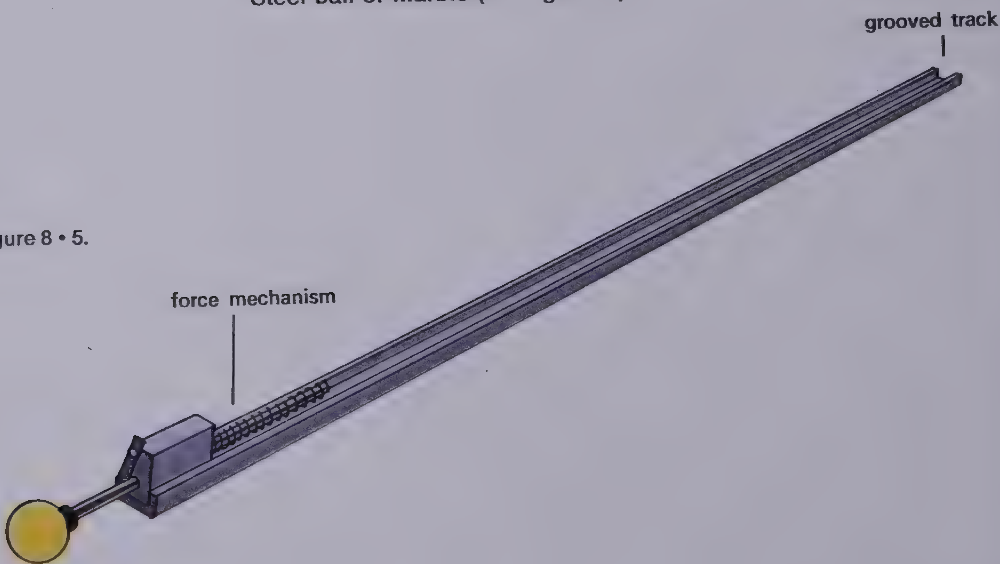


Figure 8 • 5.

PROCEDURES

A. Place the grooved track on a level surface. Gently shoot a marble or steel ball along the groove. Observe and describe its motion. Does it come to rest, or does it keep moving?

B. Change the position of the track so that the ball must roll uphill. Shoot the ball and observe its motion. Change the position of the track so that the ball must roll downhill. Repeat the procedure. Record your observations.

INTERPRETATIONS

1. Imagine that the track is very long and straight. If the slope is downhill, would you expect the angle of slope to affect the amount of time the ball will continue to roll? If so, how?
2. If the slope of the same track is uphill, would you expect the angle of slope to influence the amount of time the ball will continue to roll? If so, how?
3. What causes the ball to act as it does when the track is level?
4. What will happen if the ball is rolled with the same force along a level track that is smoother? Along a level track that is rougher?
5. If no forces act on the ball after the first push, what will happen to the motion of the ball? Why?
6. In your own words, state what you think the natural condition of an object is. (Do you think objects are naturally at rest, in motion, or—depending on other conditions—either one?)
7. What are some of the factors that could affect the motion of an object?

INVESTIGATION 8.2: The Natural Condition of an Object

(pages 178–179)

Observation and logic give students a basis for realizing that whether an object is in motion or at rest at a given time depends upon the forces it has experienced. It only *appears* that the "natural condition" of any object is to be at rest. Newton's first law of motion challenges this concept.

MATERIALS

The track may be made of wood or any other smooth material. An ordinary sheet-metal curtain rod makes an excellent track. The force mechanism may be constructed by using a two-by-four about 24 inches long, a hacksaw blade, and a notched stick made to act as a set-and-release level. The apparatus (Figure T-8 • 5) will produce relatively uniform increments of force for this investigation and others that follow.

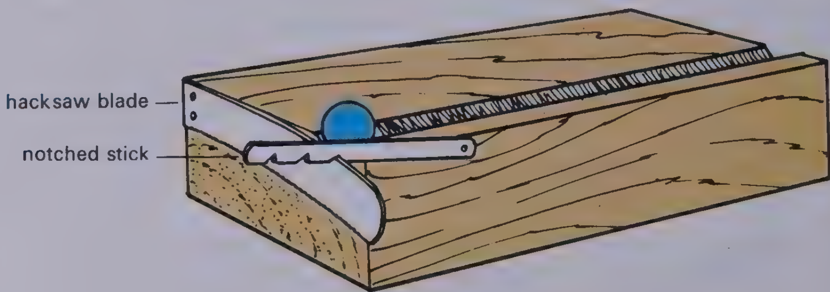


Figure T-8 • 5.
Force mechanism.

PROCEDURES

A. Students should note a *gradual* deceleration, or slowing down.
B. If the uphill slope is steep enough, the ball will come to rest and begin rolling backwards; with a downhill slope, the ball will continue to accelerate.

INTERPRETATIONS

1. The steeper the slope, the more rapidly the ball will reach the end.
2. Yes—the steeper the slope, the more rapidly the ball will come to rest and begin rolling backward.
3. External forces (friction, air resistance, and so forth) cause the ball to slow down.

4. The smoother the groove, the greater the distance the ball rolls.
5. The ball would remain in constant motion along a straight line, since no forces would act upon it to slow it down.
6. It is hoped that students will express, in their own words, Newton's first law of motion: An object in motion will continue in motion unless some force acts to stop it.
7. Some of the factors affecting the motion of an object are other objects that hit it or push on it, friction, gravity, and air resistance.

Measurement of Time

Man has been measuring time since at least 4236 B.C., the date of the earliest known calendar. It is likely that people who lived much earlier than this also had ways of measuring time. And it is certain that modern man attaches much importance to the measurement of time. You can get an idea of how important such measurement is today by recording the number of calendars and clocks you see in one day!

Why should man be so concerned about measuring time? One answer to this question is obvious: he needs to know when to perform certain actions. You, for example, must know when to leave home in the morning to arrive at school on time, what time to be in the gym for basketball practice, and what time to be ready for a date.

Unless someone invents a time machine that will "unwind" history, we can only guess at the reasons Cro-Magnon man might have wished to time his actions. But we know that he hunted herd animals, such as reindeer, which migrated at certain times of the year. We can therefore imagine he wanted to know the timing of these migrations so that he could stay with the herds he hunted.

Though we are not sure how important the measurement of time was to Cro-Magnon hunters, we can be certain that it was often a matter of life or death to some of the earliest crop-raising people. Included among them were people who farmed on the banks of the Nile River, in Africa. This location had many advantages for crop raising, one of which was that the river flooded every year *at a regular time*. In so doing, it irrigated the fields of the early Egyptian farmers. But the crops had to be ready to benefit from the floods, so the farmers had to know exactly when the river would rise. It is perhaps for this reason that the Egyptians developed the earliest known calendar.

Southwest of London, England, on the Salisbury Plain, there is a group of large stones—some weighing several tons—arranged in a curious pattern. The stones at this site (Stonehenge) are believed to have been installed about 3500 years ago by a farming people. So far, no one has proved beyond doubt just what purpose

Stonehenge served for these people. But some scientists have shown that the stones *could* have been used to calculate the time of year. Stonehenge has been measured and mapped in great detail. One scientist has recently shown that the time of year can be accurately determined by lining up the positions of sunrise and sunset with some of the large stones. Since farmers need information about the time of year—when to plant, when to harvest—this explanation of Stonehenge seems reasonable.

Figure 8 • 6. Stonehenge (aerial view).

Figure 8 • 7. Stonehenge (ground view).

Since the days of the early Nile farmers and the Stonehenge people, man has devised ever more complex ways of making a living. And his need to know when to perform certain actions has grown increasingly important. As you know, nearly everyone in today's industrial world measures time. To understand why such measurements are important in our society, we need only imagine the problems that might arise in a factory or office if everyone arrived for work at a different time. Timing is important when events require the cooperation of many people from different places.

We have mentioned only in passing two methods of measuring time: calendars and clocks. The calendar is used to measure large units of time, such as days, months, and years. As you know, the calendar was probably first invented by the Egyptians. But other agricultural peoples—for instance, the Maya of Central America—also invented calendars. This is not surprising in view of the need for accurately timing agricultural events (planting and so forth) and the fact that agriculture was independently developed by various peoples.

Clocks are used to measure small units of time, such as hours, minutes, and seconds. Sundials, one of the first clocks, originated in Babylonia before 2000 B.C. They were useless at night and on cloudy days. Because they were dependent on the sun, sundials were eventually replaced by more useful timepieces.

Figure 8 • 8. Sundials have always been useless at night and on cloudy days. What added disadvantage would they have in the modern world?

In the Orient, one of the earliest timing devices was a knotted rope. The rope was lit at one end, and the unit of time was the period required for the fire to travel from one knot to another.

Precise measurement of time will be a key requirement in many of the investigations to follow.

ON YOUR OWN: Inventing a Timing Device

We usually have little problem telling time; modern watches and clocks are dependable and available almost anywhere. During this investigation, you are asked to assume that we are living just before the time of Galileo. So you have no clocks or watches. Yet we need a way to measure short lengths of time. To do so, we must have short and equal *units* of time.

PROCEDURES

A. Each individual or team is to invent some kind of simple timing device, using materials available in the classroom or at home. The device must be suitable for measuring events that begin and end within a rather short period of time. Once your timer is complete, proceed with Procedure B.

B. Use your timer to time different events—such as how long it takes for different students to walk the length of a room or how long it takes to copy each word in this paragraph on a piece of paper. Think of other events that can be timed. You may express the time in clicks, marks, volume, or any unit your timing device requires.

INTERPRETATION

Prepare a brief report on your method of timing and describe the events you timed. For example, suppose your timer consisted of tapping a pencil lightly on the table or desk at regular intervals. Your unit of time would then be a pencil tap, instead of a second or minute.

ON YOUR OWN: Inventing a Timing Device

(page 183)

The purpose of this investigation is to prepare students for some of the timing problems they will encounter during the study of motion. It allows students to experience a problem faced by early scientists. It also provides students with an opportunity to express their individual creative ability.

MATERIALS

If there is a clock in the room, it should be covered, and watches should be put out of sight.

The following items should be randomly distributed about the room:

- Several spools of thread
- A number of cone-shaped paper drinking cups
- Several yardsticks
- Several graduated cylinders
- A can of uniform fine sand

PROCEDURES

A. It is difficult to predict what kinds of timing devices students will design. The materials listed above could be used for the construction of a water clock or sand clock. Students may use the drip of water from a faucet or their own pulse rate. Or they may design a device made from other materials.

B. Students should select their own events to time.

INTERPRETATION

Reports will depend upon the devices and activities of the teams.

INVESTIGATION 8.3: Speed

The term *speed* is part of your everyday vocabulary. We talk about the speed of automobiles, jet airplanes, and even the speed of sound and of light. This investigation is designed to show you a method of measuring speed.

MATERIALS (per team)

Grooved speed-track system (Figure 8 • 9)
Steel ball about ½ inch in diameter
Timer
Graph paper

PROCEDURES

A. Hold the steel ball against the starting post in Track 1. Release the ball and determine the time it takes the ball to reach the end of the track. Time can be measured with a click timer, with a stopwatch, or by careful observation of a sweep-second hand on a watch or clock. Teamwork is important! It is best to make several trials and calculate the *average* time for all trials.

B. Repeat the procedure, using Tracks 2 through 6. Record the average time for each track.

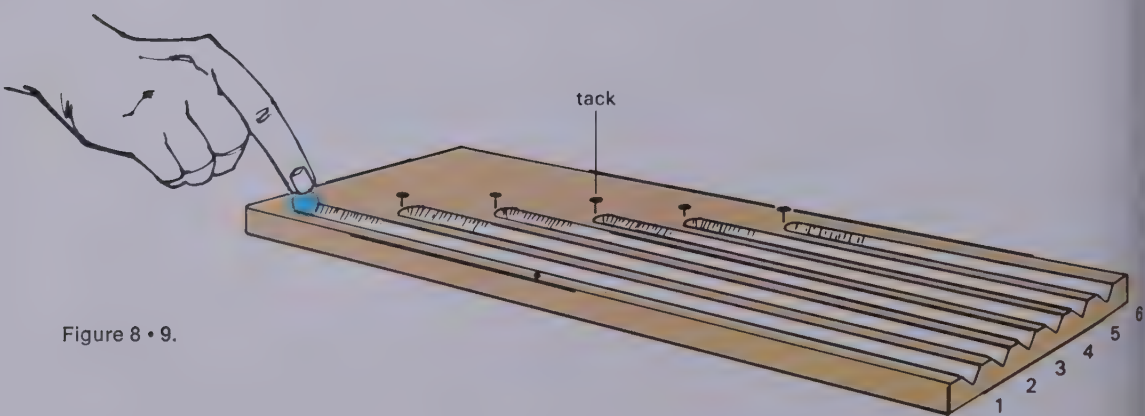


Figure 8 • 9.

C. Measure the length of each track in centimeters or inches.

D. Plot the data on a bar graph, using the horizontal axis to show distance traveled and the vertical axis to show time.

INTERPRETATIONS

1. Compare your graph with the appearance of the speed-track system. Describe similarities and differences, and suggest an explanation.
2. Assume that $s =$ speed, $d =$ distance, and $t =$ time. Change each of the following equations into a sentence:

   a. $s = \frac{d}{t}$

   b. $d = st$

   c. $t = \frac{d}{s}$
3. Suggest ways in which the design of this investigation could be improved to yield more accurate results.
4. In your own words, write out a definition of speed.
5. What is the speed of—

   a. a ball that rolls 20 cm in 4 clicks of a timer?

   b. a toy car that goes 84 cm in 6 clicks of a timer?

   c. a marble that rolls 75 cm in 5 seconds?

   d. an insect that flies 126 cm in 3 seconds?
6. How far can a horse walk in 15 minutes if its speed is 2000 cm/minute?
7. If a man runs 1000 cm/second, how long will it take him to go 5000 cm?

ON YOUR OWN: Measuring Speed

Use your ingenuity to collect data and calculate speeds for—

a. a person walking normally;

b. a person running rapidly;

c. an automobile driving past you;

d. an auto or bus in which you are a passenger;

e. a ball rolled or thrown.

INVESTIGATION 8.3: Speed

(pages 184–185)

Students should understand that time and distance must be measured in order to determine speed. Gathering data and graphing it should reinforce the idea that at a constant speed, the distance traveled increases directly with time. There will be problems involving distance, speed, and time in subsequent investigations.

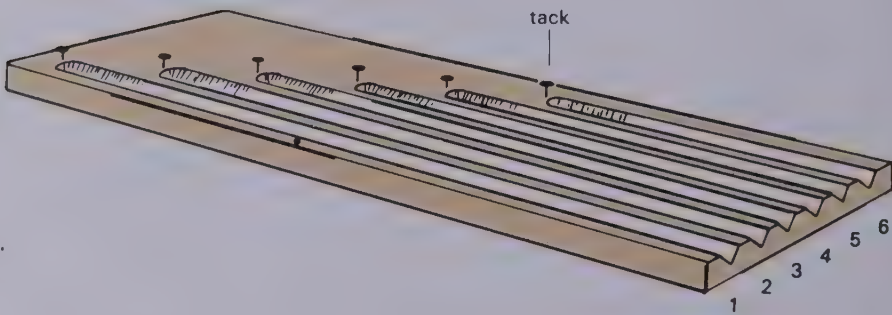


Figure T-8 • 6. Speed-track system.

MATERIALS

The wooden speed-track systems may be made in the school workshop. Proper launching techniques should reduce acceleration to a minimum. A tack, brad, or small nail at the beginning of each track provides support if the ball is held against it with a finger. When the ball is released, it should proceed down the track at a fairly constant rate of speed. The tracks should slope downhill *very* slightly so acceleration is minimized.

In place of the speed-track system, it is possible to substitute a single track with the desired distances marked off. It is necessary to use some sort of launching ramp to give the ball an initial speed. The ball need not roll far on the ramp, since greater speed will only make timing more difficult. The ball may be held near the end of the longer track by placing a pencil in front of it. The ball can then be launched by lifting the pencil. The launching will be uniform each time if the pencil is always held at the same position on the incline.

A metronome or click timer can be used to measure time in most investigations in Sections Eight and Nine. Students may experience some difficulty observing the position of the ball at the instant of a click.

This difficulty is eased if they will count rhythmically "one-two-three-four, one-two-three-four" and release the ball on the next count of "four." This helps in starting counts.

PROCEDURES

A. Each team member should become involved in some portions of the investigation. Some students will be better able to observe the position of the ball when the timer clicks than will others; some may be able to see the relationship of time and distance more readily than others.

B. No comment.

C. No comment.

D. Students should have no difficulty in plotting points on the graph if they recall similar work in the investigations on measurement.

INTERPRETATIONS

1. Some will quickly see that their graphs are quite similar in appearance to the series of tracks. This provides students with a chance to see that some graphs bear a visual resemblance to the actual events they summarize.
2. Students should be able to express the meaning of each equation and relate their explanation to the graph. This is not intended as an exercise in algebra, but rather as a chance for the students to translate an equation in symbols to an equation in words. This is an essential step in the process of problem solving.

   a. $s = \frac{d}{t}$: to find the speed, divide the distance traveled by the time required to travel that distance.

   b. $d = st$: to find the distance traveled, multiply the speed by the time during which that speed was maintained.

   c. $t = \frac{d}{s}$: to find the time required to travel a certain distance, divide the distance by the speed. Without being given an opportunity to think and write out statements of their own, students are apt to substitute words for symbols and not see how the words can be applied to problem solving.
3. Students may recognize that *some* "speeding up" occurs if the track is slightly inclined. It might be helpful to ask if the longer tracks yield less constant data than the shorter tracks. More accurate timing and launching mechanisms could improve the experimental design and the resulting data.
4. Student answers will vary. They should be able to express speed as the *average distance traveled in a certain unit of time.*

5. The speed is—

   a. $\frac{20 \text{ cm}}{4 \text{ clicks}} = 5 \text{ cm/click}$

   b. $\frac{84 \text{ cm}}{6 \text{ clicks}} = 14 \text{ cm/click}$

   c. $\frac{75 \text{ cm}}{5 \text{ sec}} = 15 \text{ cm/sec}$

   d. $\frac{126 \text{ cm}}{3 \text{ sec}} = 42 \text{ cm/sec}$

6. $2000 \text{ cm/min} \times 15 \text{ min} = 30{,}000 \text{ cm}$

7. $\frac{5000 \text{ cm}}{1000 \text{ cm/sec}} = 5 \text{ sec}$

Understanding Force

Force was used by man long before he realized what it was. He applied force when he lifted a stone or threw a spear. Today we use many devices to produce force: jet engines, electric motors, gasoline powered engines, and atomic energy reactors. We have talked about the attractive forces between atoms and between molecules, and we have seen in Investigation 8.1 that there is a force called *gravity*.

All of these examples involve lifting, pushing, pulling, or attracting. Force is any influence that tends to cause matter to move. The word *tends* is important. For example, if you attempt to lift one end of an automobile, you are exerting force, even though the car is too heavy to lift. Or, if you lean against a solid wall, you exert force, even though the wall does not move.

It takes force to compress, stretch, or bend a spring. The atoms in a spring are arranged in a particular way. To bend them out of their pattern requires that the electrons holding them together be crowded in some places and thinned out in others. Where the electrons are crowded together, they repel each other more strongly and give the metal spring a tendency to return to its original shape. The more you bend the material out of its normal shape, the more crowded the electrons become and the greater is the tendency of the material to return to its original shape. One way to measure this tendency is to observe the effect of a spring on a steel ball.

INVESTIGATION 8.4: Force and Bending *(Optional)*

At different times, an object can have different speeds. This investigation should help you to find one of the factors that determines the speed of an object.

MATERIALS (per team)

Ruler
Grooved track and force mechanism (Figure 8 • 5)
Steel ball or marble
Timer
Graph paper

PROCEDURES

A. Copy Figure 8 • 10 in your notebook and record the data gathered from this investigation.

Trial	*Change in Length of Spring*	*Time for Ball to Travel Length of Track*	*Speed of Ball*
1.			
2.			
3.			
4.			
5.			

Figure 8 • 10.

B. Measure the length of the track and spring. Compress the spring a small fraction of its length. Record the length of the compressed spring. Using this setting of the least spring tension, launch the steel ball or marble and measure the time required for the ball to travel the length of the track. Repeat several times and determine the average speed.

C. Launch the steel ball, using a setting of greater spring tension on the force mechanism. Calculate the average speed from several trials.

D. Continue investigating the relationship between spring tension

(compressed length) and the speed of the ball, using other settings on the force mechanism.

E. Plot your data on a graph, showing speed on the vertical axis and force (represented by the changes in spring length) on the horizontal axis.

INTERPRETATIONS

1. How is the amount of force you used related to the speed of the ball?
2. How is the amount of force you used related to the shape of the spring?
3. When you pull back the spring, what happens to the average distance between atoms in the spring?
4. What kind of particles make up the outside part of each atom?
5. What do these kinds of particles do to each other?
6. How would a decrease in distance between atoms change the way that the outside parts of atoms affect each other?
7. How is your model for the structure of matter related to the ability of a spring to exert force?

ON YOUR OWN: Designing a Method for Measuring Speed

So far you have been given one idea for measuring speed—the speed track.

Review what you know about the definition of speed $\left(s = \frac{d}{t}\right)$.

Next, design or obtain some kind of device to measure speed over short distances (within the classroom). You will also need some method of measuring time.

No hints will be given. You must use your own skill and imagination in carrying out this investigation. Your work should be done after school or at home.

When you have completed this individual or group project, you should demonstrate it to the class.

INVESTIGATION 8.4: Force and Bending *(Optional)*

(pages 186–188)

Students should grasp the relationship between the force they exert on the spring, the distortion (change in length) this force produces in the spring, and the speed acquired by a ball as a result of that force. These three quantities are directly proportional, and an increase in one can only occur if the other two are increased proportionally.

PROCEDURES

A. No comment.
B. The track must be level. The same ball should be used in Procedure B, C, and D. The force setting used should be the least that will keep the ball rolling at a steady speed.
C. Four or five trials should be sufficient to calculate an average speed.
D. No comment.
E. The purpose of this procedure is to emphasize that the amount of force exerted on the ball depends on the amount of bending in the spring.
F. Some students may need help in setting up the graph. The graph should show a direct relationship between amount of spring tension and speed of the ball. Figure T-8 • 7 gives sample data. The length of the track was 112 cm.

Trial	*Change in Length of Spring*	*Time for Ball to Travel Length of Track*	*Speed of Ball (cm/click)*
1.	1.0 cm	12 clicks	9.4 cm/click
2.	1.5 cm	10 clicks	11.2 cm/click
3.	2.0 cm	8 clicks	14.0 cm/click
4.	2.5 cm	6 clicks	19.0 cm/click
5.	3.0 cm	5 clicks	22.4 cm/click

Figure T-8 • 7. Sample data. Length of track = 112 cm.

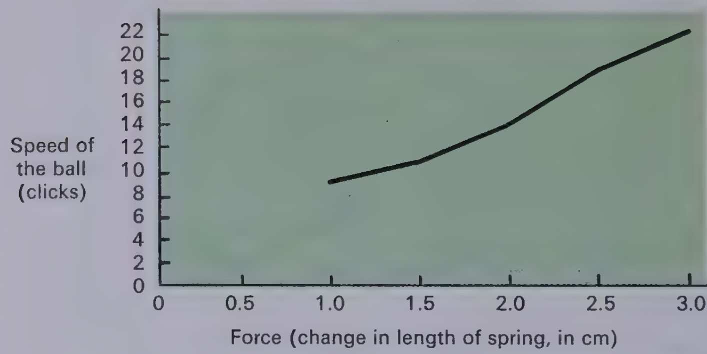


Figure T-8 • 8. Graph of sample data.

INTERPRETATIONS

1. Larger forces produce larger speeds.
2. The larger the force, the more the spring is compressed.
3. The average distance between atoms decreases when the spring is compressed.
4. Electrons make up the outer part of atoms.
5. Electrons repel each other.
6. Decreasing the distance between atoms brings electrons closer together and makes them repel each other more.
7. Students should indicate that compressing a spring forces atoms closer together, and the force which the spring exerts results from the repulsions of electrons where they are crowded closer together than normal.

ON YOUR OWN: A Method to Measure Speed

(page 188)

As with other investigations of this kind, we cannot predict what kind of method or device students may design or obtain. You may be surprised by their ingenuity.

Here are a few methods:

1. Students can determine the time a ball takes to travel the length of a ruler with a grooved center.
2. Some students may bring in a windup toy and record the distance it travels in a measured period of time.

3. An electric-powered train (preferably battery type) may be brought to class. If a portion of the track is straight, this distance may be measured and the time for the train to travel a certain distance determined.
4. Some students may bring live animals (snails, lizards, etc.) and record the time it takes the animal to traverse a homemade track.

The importance of this investigation is that students realize that the average time required for an object to travel a certain distance is called *speed*.

INVESTIGATION 8.5: Force and Stretching *(Optional)*

Force has been defined as a push or a pull. Can you find a relationship between the amount of force, the behavior of the spring, and your model for the structure of matter?

MATERIALS (per team)

Force gauge (Figure 8 • 11)
Masking tape
6 to 8 identical objects (marbles, steel balls, nails, screws, or other objects of convenient size and weight)

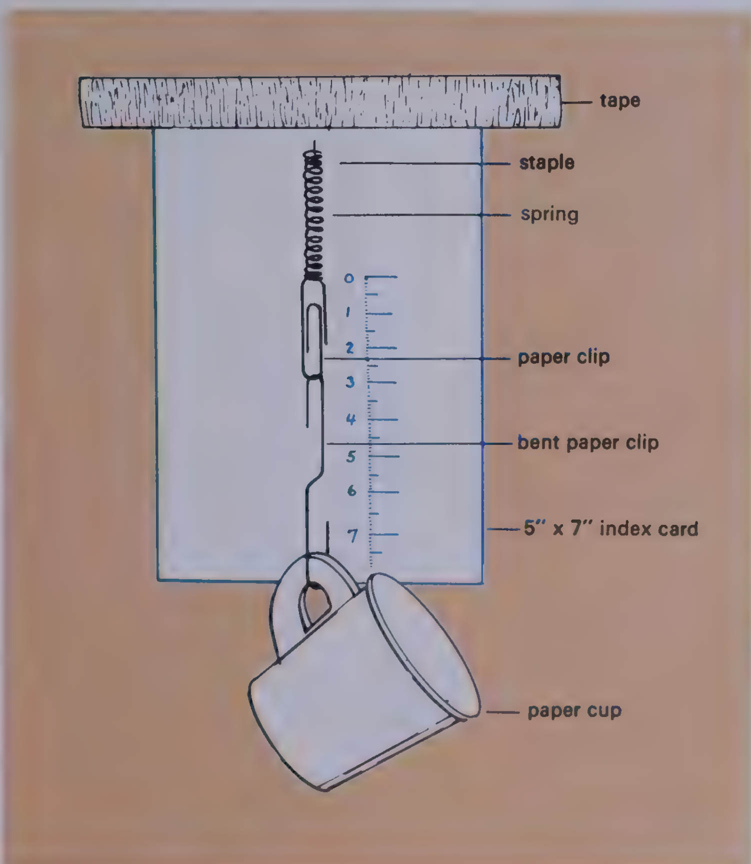


Figure 8 • 11.
Force gauge.

PROCEDURES

A. Tape the force gauge to the edge of a table or desk so that the spring, paper clips, and cup hang down along the scale on the card.

B. Read the position of the lower end of the spring on the scale. Be sure that your eye is level with the end of the spring when you take the reading.

C. In your notebook, prepare a chart similar to the one shown in Figure 8 • 12. Include numbers for four, five, and six objects.

Figure 8 • 12.

Number of Objects	*Scale Reading (in cm)*	*Change in Scale Reading*
0		
1		
2		
3		

D. Put one object in the cup and record the scale reading. Add identical objects, one at a time, and record the scale reading each time.

E. Remove all objects from the cup and check to see that the scale reading is the same as it was when you began. If it has changed, you will need to repeat Procedure D.

INTERPRETATIONS

1. Calculate the change in the length of the spring caused by each additional object. Record these changes in the third column on your chart. Look for a pattern in the changes.
   a. What is the pattern?
   b. What explanation can you give for the pattern?
   c. How might you explain any irregularities in the pattern?
2. Use your model of the structure of matter to explain the data.

INVESTIGATION 8.5: Force and Stretching *(Optional)*

(pages 189–190)

By simple measurements students can discover that the pull of gravity is proportional to the amount of matter in a sample. They also become familiar with the type of force gauge used to measure the force of friction in Investigation 8.6.

MATERIALS

The small spring found inside retractable ball-point pens works very well in this investigation. You may want to have the students prepare their own force gauges at home, or you may ask several of your students to prepare enough for the entire class. The bent paper clip is included to permit removal of the paper cup so the force gauge can be used to measure frictional force in the next investigation. The scale card should be stiff enough to permit reliable readings. It can be an index card, cardboard, or a small piece of plywood.

The scale can be marked directly on the card, or a ruler may be taped onto the card.

Be sure that the springs are not too stiff and that their change in length increases in proportion to the load on them. It may help to stretch the springs a number of times before using them. The cup can be a commercial paper cup, a small tin can, or a cone made from a triangular piece of paper, 8 inches on a side.

The objects to be placed in the cup should all be the same weight. They may be marbles, nails, bolts, or any other easily obtained items. Assemble a force gauge and test the items in advance to be sure they produce an easily observable effect. They should be light enough so that several of them used at one time will not increase the length of the spring by more than about 20 percent. But the weight of one should be enough to produce an easily observable reading on the scale.

If the force gauges are prepared before class, this investigation should take no more than a few minutes.

PROCEDURES

A. If you have ring stands and clamps handy, use them to support the force gauges at a more convenient height.
B. Students may take their readings from the bottom of the first paper clip, but emphasize that readings must be consistent.
C. Point out that the third column in the chart is to be completed in Interpretation 1.
D. No comment.

E. If the spring has not been broken in or if it is wearing out, it may not return to the original zero mark. If repeated trials do not give satisfactory results, replace the spring.

INTERPRETATIONS

1. A typical chart is as shown in Figure T-8 • 9.

Figure T-8 • 9.

Number of Objects	*Scale Reading (in cm)*	*Change in Scale Reading*
0	14.35	
1	14.65	0.30
2	14.95	0.30
3	15.25	0.30
4	15.55	0.30

Notes on the data: The spring was 3.5 cm long. The objects were 2 oz. fish weights (1/2 inch diameter). The scale was in centimeters, the divisions were millimeters, and readings were to the nearest half millimeter.

a. The spring increased about 0.3 cm in length for each object added to the container. (The change will depend on the strength of the spring and on the weight of the objects.)

b. The latitude of this question permits a wide variety of answers. The answers should deal with the design of the experiment and with the nature of force. Student answers may include a statement such as, It got longer by the same amount each time, because the same kind of object was always added to the cup.

c. Variations in readings may arise from errors in reading or from frictional drag of the spring or cup against the card.

2. In Section Three, students found that the attraction between particles might be electrical. Stretching the spring rearranges some of its bonding electrons. Where electrons are crowded together, they tend to push the atoms back into their original positions. The more the electrons are crowded together, the greater the force with which they repel and the greater the tendency of the spring to return to its original shape.

INVESTIGATION 8.6: Friction

Friction is the resistance an object experiences as it moves on or through another material. You probably are familiar with friction. You may have used the effect of friction to warm your hands by rubbing them together. Space vehicles returning to earth depend on the friction of air to slow them down. The movement of a solid body over another surface is resisted by a force called friction. The movement of an object through fluids such as air and water is resisted by friction.

What factors affect frictional forces? How are these factors related to the structure of matter? These questions are of great theoretical and practical importance. They are important in building our understanding of the structure of matter. They are of practical importance because our society depends on transportation, and the control of friction is one of the biggest problems in transportation.

MATERIALS (per team)

Force gauge (used in Investigation 8.5)
3 wooden blocks (Figure 8 • 13)
Sheet of sandpaper
Pane of glass
2 pieces of glass tubing or rods (4-inch lengths)
2 rubber bands
Masking tape

PROCEDURES

In Procedures A through E, you are asked to determine whether the texture (rough, smooth), shape (curved), and area (size) of surfaces in contact affect the amount of friction between objects.

A. Lay the force gauge on the desk or table, and straighten out the spring and paper clips. The free end of the second clip should extend beyond the edge of the gauge. Pick up the free end and hold it so that the spring is straight but not stretched. Record the scale reading (at the end of the spring).

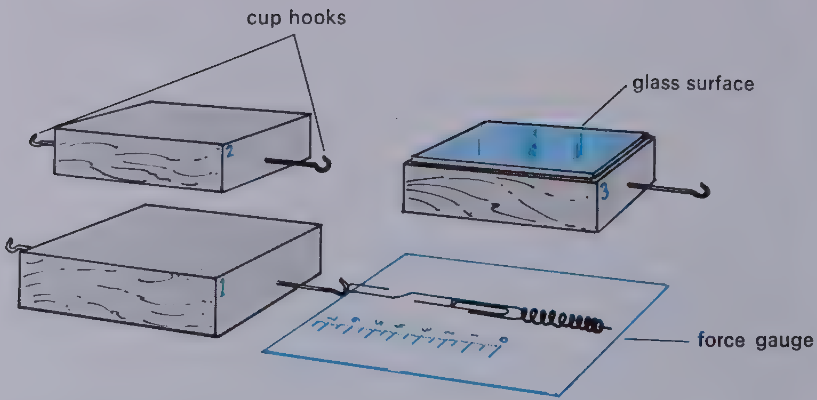


Figure 8 • 13. Force gauge and wooden blocks to be used in Procedures A–K.

B. Number the blocks as shown in Figure 8 • 13. Place Block 1 on the sandpaper, with one of the large sides down. Attach the free end of the force gauge to the hook on the block (Figure 8 • 13). Pull on the force gauge so that the block slides at a steady speed over the sandpaper. Take a reading on the force gauge scale. Record the reading.

C. Place the block on the pane of glass (same side down). Pull on the force gauge so that the block slides at a steady speed. Record the reading on the force gauge scale.

INTERPRETATIONS

1. Glass is made from melted sand. How can you explain the difference between the force required to pull wood over sandpaper and the force required to pull wood over glass?
2. How can this difference in force be related to the structure of matter?

PROCEDURES

D. Turn Block 1 so that one of its smaller sides is down. Do you think it will require more, less, or the same amount of force to pull the block in this position as compared with the force

required in Procedure C? Write down your prediction. Now test your prediction by pulling the block over the glass. Pull on the force gauge so that the block slides with a steady speed. Record the reading.

INTERPRETATIONS

3. Is the amount of friction between objects related to the area of the surfaces in contact when the total weight stays the same?

PROCEDURES

E. Lay two glass rods or tubes parallel to each other (about 1 inch apart) on the pane of glass. Put Block 1 on top of them and pull it with the force gauge so that it rolls with a steady speed. Record the reading.

INTERPRETATIONS

4. Imagine you can see individual molecules. Sketch the motion of molecules of wood and glass in Procedure D. Make another sketch showing the motion of molecules of glass in the rods under the wood in Procedure E.

PROCEDURES

In Procedures F through I, you are asked to determine whether the *kind of material* that makes up the surfaces in contact affects the amount of friction.

F. Place Block 3—glass side down—on the pane of glass. Measure the force required to slide the block at a steady speed across the plate of glass. Record the reading on the scale.
G. Turn the block over so the glass surface is up. Use the force gauge to pull the block at a steady speed on the glass plate. Record the reading of the force gauge.

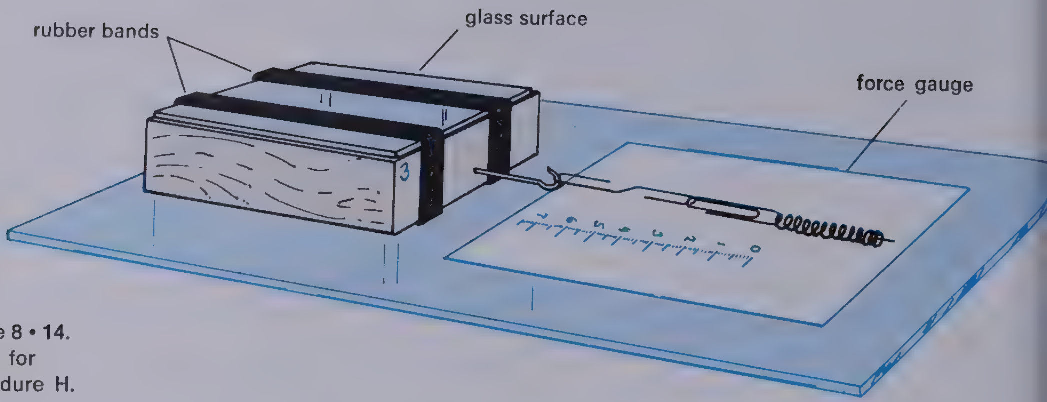


Figure 8 • 14.
Setup for
Procedure H.

H. Put two rubber bands around Block 3 as shown in Figure 8 • 14. Be sure the rubber bands are not twisted. With the rubber bands acting as runners, pull the gauge so that the block moves at a steady speed over the glass. Record the reading.

INTERPRETATIONS

5. List several properties of rubber that you think make it useful for vehicle tires.

PROCEDURES

I. Remove the rubber bands and replace them with two pieces of masking tape as shown in Figure 8 • 15. Be sure the sticky side of the tape is out. Try to pull the block over the glass at a steady speed with the gauge. Record your observations.

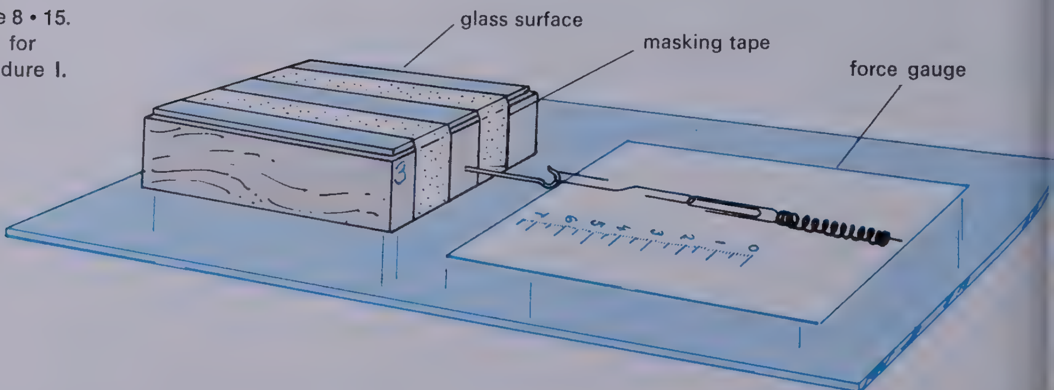


Figure 8 • 15.
Setup for
Procedure I.

INTERPRETATIONS

6. Explain the result of Procedure I in terms of the behavior of the particles that make up the surface of masking tape. You will want to take into account both the roughness of the surface and the type of material involved.

PROCEDURES *(Optional)*

In Procedures J and K, you will investigate the effect of weight on friction.

J. Prepare a chart similar to the one shown in Figure 8 • 16. Use your force gauge to measure the force needed to pull Block 1 at a steady speed on a smooth level surface, such as a counter top. Repeat, using Blocks 1 and 2 hooked together, one behind the other. Record the reading. Repeat, using all three blocks hooked together, in single file.

Blocks		*Scale Reading*
	1	
Hooked together	1 and 2	
	1, 2, and 3	
Stacked	1 and 2	
	1, 2, and 3	

Figure 8 • 16.

K. Unhook the second and third blocks. Place Block 2 *on top of* Block 1. Pull the two blocks over the same surface used in Procedure J and record the reading. Then stack the third block on top of the others. Pull the three blocks and record data on the chart.

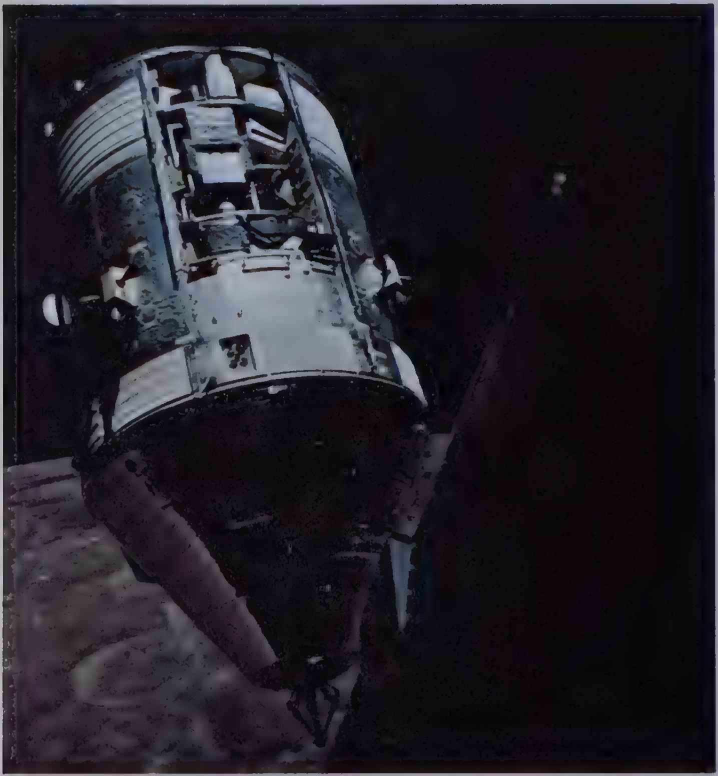
INTERPRETATIONS

7. Does the amount of friction depend on the area of the surfaces in contact when the weights are the same?

A. Ice skaters

The *Apollo 17* command and service modules, photographed from the lunar module Challenger.

B.



A summer highway scene in the Midwest

Friction

A winter highway scene in the Midwest

Figure 8 • 17. Arrange the photos to indicate a range of friction from the least to the greatest. List several ways that friction could be increased for the cars in *D*. In which photo does gravitational pull provide the least opportunity for friction to exist?

A Dialogue on Friction

Friction, like other natural phenomena, might be explained in terms of demons. Before you dismiss this idea completely, imagine that you and a neighbor called Faustus are discussing the matter. Faustus, who believes in the demon theory, begins by asking, "How do you know that it is friction that brings a rolling ball to a stop and not demons?"

YOU. I don't believe in demons.
FAUSTUS. I do.
YOU. Anyway, I don't see how demons can make friction.
FAUSTUS. They just stand in front of things and push to stop them from moving.
YOU. I can't see any demons even on the roughest table.
FAUSTUS. They are too small, also transparent.
Y. But there is more friction on rough surfaces.
F. More demons.
Y. Oil helps.
F. Oil drowns demons.
Y. If I polish the table, there is less friction and the ball rolls farther.
F. You are wiping the demons off; there are fewer to push.
Y. A heavier ball experiences more friction.
F. More demons push it; and it crushes their bones more.
Y. If I put a rough brick on the table I can push against friction with more and more force, up to a limit, and the block stays still, with friction just balancing my push.
F. Of course, the demons push just hard enough to stop you moving the brick; but there is a limit to their strength beyond which they collapse.
Y. But when I push hard enough and get the brick moving there is friction that drags the brick as it moves along.
F. Yes, once they have collapsed the demons are crushed by the brick. It is their crackling bones that oppose the sliding.[1]
Y. I cannot feel them.
F. Rub your finger along the table.
Y. Friction follows definite laws. For example, experiment shows that a brick sliding along the table is dragged by friction with a force independent of velocity.

---

[1] If Faustus has the equipment he should offer you a microphone attached to a glass table, with connections to an amplifier and loudspeaker. Then if you roll a steel ball along the table you will indeed hear noises like crushing demons.

F. Of course, same number of demons to crush, however fast you run over them.

Y. If I slide a brick along the table again and again, the friction is the same each time. Demons would be crushed in the first trip.

F. Yes, but they multiply incredibly fast.

Y. There are other laws of friction; for example, the drag is proportional to the pressure holding the surfaces together.

F. The demons live in the pores of the surface; more pressure makes more of them rush out to push and be crushed. Demons act in just the right way to push and drag with the forces you find in your experiments.

By this time, Faustus' game is clear. Whatever properties you ascribe to friction he will claim, in some form, for demons. At first his demons appear arbitrary and unreliable; but when you produce regular laws of friction he produces a regular sociology of demons. At that point there is a deadlock, with demons and friction serving as alternative names for a set of properties—and each debater is back to his first remark.[2]

FOR FURTHER DISCUSSION

1. Who do you think presented the best explanation for friction —you or Faustus? Why?
2. Develop arguments for the existence of demons by comparing the behavior of a block sliding on sandpaper and the behavior of the same block sliding on glass. How do you think demons in sandpaper might be different from demons in glass? Use the same examples to develop arguments *against* demons.

---

[2] Eric M. Rogers, *Physics for the Inquiring Mind* (Princeton, N.J.: Princeton University Press, 1960), pp. 343–345. Used by permission of the publisher.

INVESTIGATION 8.6: Friction

(pages 191–195)

The procedures in this investigation should help students to identify the factors that influence the size of frictional forces. The influence of surface contact and of shape are investigated first (A–E), and the effect of the kind of material involved is tested in Procedures F–I. The optional part of the investigation (J–K) should reinforce the idea that sliding friction is independent of contact area when weight remains constant.

MATERIALS

NOTE: *See Investigation 8.5 for details on the construction of the force gauge.*

The size of the blocks of wood is not critical, but all three should be similar. They should be rectangular and heavy enough to give a reading on the force gauge when they are pulled on a smooth surface. They should be light enough so that their combined weight can still be measured on the force gauge. Insert cup hooks in the ends of the blocks (Figure 8 • 13).

Glue a piece of glass or a microscope slide to one side of Block 3 with epoxy or some other cement that bonds to glass. The glass should be a little smaller than the side of the block, to minimize the chance of a student being cut. The larger pane of glass—on which the blocks will be pulled—should be at least three times as long as the blocks, so the students can get a reading on the force gauge as the blocks slide.

The sandpaper should be about the same size as the pane of glass.

PROCEDURES

A. The scale readings should be made at the end of the spring (where it is hooked onto the paper clip), as in Procedure B of Investigation 8.5.

B. Since the coefficient of friction is not being determined in this investigation, it is not critical that the speed of the sliding block be constant. So that results of different procedures will be comparable, the speed should be fairly constant and as nearly equal as possible from one trial to another. Under no circumstances should the motion be jerky, since it is not possible to obtain a valid reading of the force gauge under such conditions. When the block is pulled over sandpaper, there may be some small irregularities in motion, so the readings of the force gauge should be averaged.

C. The reading on the force gauge should be much lower than in Procedure B. The actual difference will depend on the weight of the block, the finish on the block, the strength of the spring, the coarseness of the sandpaper, and the scale.

INTERPRETATIONS

1. Since glass is much smoother than sandpaper, there is less chance that atoms in glass would interact with atoms in the block of wood.
2. The rough edges of the sand particles permit some atoms from the sand to stick in between the atoms that make up wood. The atoms in the sand particles get in the way of the atoms on the surface of the block, and they have to be pushed out of the way before the block can slide ahead.

PROCEDURES

D. Most students will predict that turning the block on edge changes the amount of force needed to pull it. Allowing for experimental error, there should be no difference in the force needed to slide the block in either position. If the block is on edge, the amount of surface area has been *decreased;* but if the weight of the object is resting on a smaller area, the contact pressure has been proportionally *increased*. The amount of frictional force depends on the texture and shape of the surfaces in contact and on the weight of the object being pulled. The size of the contact area is not a factor when the weight is held constant.

INTERPRETATIONS

3. The frictional force of objects sliding on a surface does not seem to depend on the size of the surfaces in contact when the weight is constant.

PROCEDURES

E. The block should roll so easily that it is difficult to get a reading on the force gauge.

INTERPRETATIONS

4. Student sketches should be similar to Figure T-8 • 10.

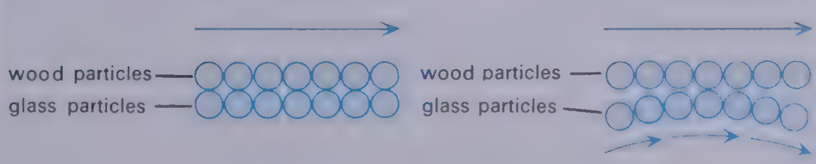


Figure T-8 • 10.

PROCEDURES

F. Have students make sure that both glass surfaces are clean and dry before they begin this procedure.

G. Depending on flatness, cleanliness, and the finish on the wood, the frictional force probably will be a little less in Procedure F than it was in G.

H. The reading should be much higher than in Procedures F and G.

INTERPRETATIONS

5. From this exercise students should note the relatively high friction associated with rubber as important in preventing skids. Other properties: it won't leak air, it is flexible, it is easily formed into shape, and it can be repaired.

PROCEDURES

I. The tape should go around the block lengthwise, with the adhesive side out. Each strip should be as tight as possible, with the ends overlapped.

The motion of the block will be jerky. It will be difficult, if not impossible, to get a dependable reading of the force gauge, but the reading at which the block starts to slide (and probably jump) ahead should be quite high.

INTERPRETATIONS

6. Masking tape does not appear to be as smooth as glass, but it appears to be smoother than sandpaper. Its roughness might account for some of the friction, but the properties of the atoms that make up the surface of the tape must be responsible for the much greater frictional force. Adhesive materials form bonds with the surfaces to which they adhere, or they are squeezed into pits and depressions in those surfaces.

PROCEDURES *(Optional)*

J. If the blocks are of the same weight and type of surface, then the force needed to pull two should be just twice the force needed to pull one. The force needed for three should be three times the force for one.

K. The force needed to pull two blocks hooked together should be the same as that needed to pull two blocks stacked one on top of the other. Similar results should be obtained for three blocks.

INTERPRETATIONS

7. The answer to this question should have been found in the results

of Procedures C and D. Using more than one block (Procedures J and K) only serves to emphasize that the force of friction depends on the composition and shape of the surfaces in contact and on the weight of the sliding object—not on the amount of surface area in contact when the weights are held the same.

FOR FURTHER DISCUSSION

The following questions may be used to summarize the experiment on friction and to emphasize the relationship of the structure of matter and the phenomenon of friction:

a. How could the force of friction be related to the electrical nature of matter? (The nucleus of an atom has all of the positive charge, and the outer region of every atom is occupied by electrons. Since like charges repel each other, friction could result from electrical repulsion.)

b. When two surfaces are pushed together, what is the effect on the electrons that make up the surfaces? (They are pushed closer together, so they repel each other with more force.)

c. If two objects are pressed together at the same time one is sliding over the other, how will this affect the frictional force? Why? (The frictional force will be increased. Electrons from the two surfaces will be pushed closer together. They will then repel each other with greater force, making it more difficult to slide one object over the other.)

d. If the surfaces are fairly rough, how will this affect the possibility of electrons from both surfaces approaching each other very closely in some places? (If the surfaces are rough, there is a good chance that electrons from the two surfaces will come quite close to each other at certain points.)

e. If the surfaces are smooth, are electrons from the two surfaces likely to approach each other more closely in some places than in others? (No, if the surfaces are very smooth, they should not be able to come any closer in one place than in another.)

f. Would you expect greater friction between smooth surfaces or rough surfaces? (Greater friction between rough surfaces.)

g. When a fluid such as oil is placed between the surfaces, how might the forces of electrical repulsion between electrons on the two surfaces be affected? (The oil separates the surfaces, so interaction between the solid surfaces is decreased.)

h. If you could put a fluid such as a gas between two surfaces, how would the electrical repulsion between the two surfaces be affected? (It would be reduced.)

NOTE: *If dry ice is available, it might be used to provide an interesting example of the reduction of friction by a cushion of gas between objects. Dry ice is solid carbon dioxide. When it warms up, it changes directly into a gas. This gas separates the surface of the block of dry ice from the surface on which it rests.*

CAUTION: *Since the temperature of dry ice is −79°C, use tongs or heavy gloves to handle it.* Do not touch it *with your hands.*

Figure 8 • 17. Friction

(pages 196–197)

This series of photos is intended to help students visualize friction as observed in everyday life. The inquiry is not intended to be difficult and can be used as part of an individualized study program.

Students may disagree with the answers given here. And they should be allowed to do so.

Questions

Some reasonable answers:

The range of friction from least to greatest would be *B, A, D, C.* Friction could be increased for the cars in the winter highway scene by snowplowing, use of sand, tire chains, or snow tires. A spacecraft normally encounters little or no friction after leaving the earth's atmosphere and gravitational influence. We can't say there is absolutely no friction because extremely small pieces of meteors and asteroids may strike the craft, thus exerting a minute frictional force. The frictional forces upon reentry, of course, are enormous and are due to the resistance of the atmosphere and the pull of gravity. Thus the need for durable heat shields on spacecraft.

A Dialogue on Friction

(pages 196–197)

The dialogue with Faustus further illustrates the role of a model in science and shows how easy it is to explain physical phenomena in terms of demons or any other imagined agents of unlimited capability. The dialogue should engender considerable class discussion and (we hope) result in more thorough understanding of the nature of science and scientific models.

The passage below is a continuation of the discussion about demons, from Rogers, *Physics for the Inquiring Mind.*[T1] After your class has finished a discussion of "A Dialogue on Friction," you might want to read this passage to them. (If this material is read before the class discussion, fewer students are likely to participate.)

> You realize that friction has only served you as a name: it has established no link with other properties of matter. Then, as a modern scientist, you start speculating on the molecular or atomic cause of friction, and experimenting to test your ideas. Solids are strong; they hang together. Their component atoms must attract with large forces at short distances. When solid surfaces slide or roll on each other, small humps on one get within the range of atomic attractions of local humps on the other and they drag each other when the motion tries to separate them. Friction, then, may be an atomic dragging, which is likely to make one surface drag small pieces off the other. That has been investigated experimentally. After a copper block has been dragged along a smooth steel table, microphotographs show tiny copper whiskers torn off on to the steel. Also chemical tests show that a little of each metal rubs off on to the other.
>
> At last you have a good case for *friction:* it is a scientific name for some well-ordered behavior that we can now link with other knowledge. It is atomic or molecular dragging, caused by the same forces that make wires strong and raindrops round. Its mechanism can be demonstrated by photographs and by chemical analysis. Its laws can even be predicted by applying our knowledge of elasticity to the small irregularities of surfaces. Friction has joined other phenomena in a general explanation.
>
> And now we can state the full case against demons: they are arbitrary, unreasonable, multitudinous, and over-dressed. We need a special demon with peculiar behavior to explain each natural event in turn: therefore we need many kinds and vast numbers of them. And we have to clothe them with special behaviors to fit all the facts. We now prefer something more economical and comfortable; a consistent body of knowledge, with strong ties to experiment—and with cross checks and interlinkages to assure us of validity—all expressed in as few general laws as possible. Even where we meet new events that we cannot explain, we would rather speculate cautiously than invent a demon to calm some fear of mystery.

[T1] Eric M. Rogers, *Physics for the Inquiring Mind.* (Princeton, N.J.: Princeton University Press, 1960). Used by permission of the publisher.

The Force of Gravity

Until the time of Isaac Newton (1642–1727), men generally believed that the sun, moon, and stars behave according to rules of motion that are different from the rules of motion on earth. They believed that heavenly objects are circular in shape, move in circles, and (with the exception of planets) have moved through the same circular pattern since the beginning of time. By assuming that each planet moves on a circle which rolls on another circle, early astronomers were able to account for the apparent ability of planets to "wander among the stars."

All this was a logical extension of their model, which separated the heavens from the earth and assumed that each has its own unique rules for the behavior of matter. Today we know that earth is just one body among the billions scattered through the universe. And we believe our planet and everything on it behave according to the same rules that apply elsewhere.

Man's desire to fit the movements of planets into the old model led to careful observations—which, oddly enough, eventually brought about the downfall of the old model. Newton examined the data collected from these observations. He decided that the movements of the planets could result from the same kind of force that causes objects to fall downward on earth. To convince other people of this hypothesis, he needed to provide some kind of proof that his model was more valid than the one people had accepted for thousands of years. He developed a new kind of mathematics, called *calculus*, and used it to show that only a force such as the one he described could account for the paths of the planets. This force was, of course, gravity.

Newton's statement of the law of gravity and other laws of motion was so complete that it explained many other things which had puzzled astronomers. He also made predictions about the shape of the earth and described the conditions necessary for an artificial satellite to orbit the earth. Some of his predictions were so precise that we have been able to test them only recently, by observation from satellites. Newton's explanation of the motion of falling objects (which includes planets, stars, and moons) is an

outstanding example of a successful model. His model has been tested by experiments, and it can be used to make many useful predictions about the movements of objects anywhere. You will not be asked to investigate all of the problems Newton solved. On the other hand, you will not simply memorize his formulas. In Investigation 8.2, you were asked to describe a characteristic of objects that Newton called *inertia*.

INVESTIGATION 8.7: Motion and the Force of Gravity

This investigation has been designed so that you can gather information about the way objects respond to the force called *gravity*.

MATERIALS (per team)

Force gauge (same as in Investigation 8.5)
2 steel balls (one larger than the other)
2 grooved tracks
Block of wood
Timer
Meterstick

PROCEDURES

A. Using the force gauge, measure the force with which gravity pulls on the large steel ball. Next use the force gauge to measure the pull of gravity on the small steel ball. Record your observations carefully.

INTERPRETATIONS

1. The large steel ball is how many times heavier than the small steel ball? (Divide the change in the spring length resulting from the force of gravity on the large steel ball by the change resulting from the force of gravity on the small one.)
2. Would you predict that the speed of the large steel ball will change more rapidly than that of the small one if the two are falling?

Figure 8 • 18. Setup for Procedures B–E. A 5/100 ratio means that the track is raised 1 cm for every 20 cm of its length.

Trial	*Time for Small Steel Ball to Roll 40 cm on Level Track*	*Speed*
1.		
2.		
3.		
Average Time		*Average Speed*

Figure 8 • 19.

PROCEDURES

B. Set up the tracks as shown in Figure 8 • 18. Mark a starting point at the upper end of the sloping track. Hold the end of a pencil in the groove at this point and place the small steel ball against it. Release the ball by lifting the pencil and measure the time required for the ball to roll *40 cm on the level track.* Record your data on a chart (Figure 8 • 19).

INTERPRETATIONS

3. Calculate the average speed of the small steel ball on the level track. (Divide 40 cm by the average number of clicks it took to roll 40 cm on the level track.)

PROCEDURES

C. Repeat Procedure B using the large steel ball in place of the small one. Record your data on a chart (Figure 8 • 20).

Trial	*Time for Large Steel Ball to Roll 40 cm on Level Track*	*Speed*
1.		
2.		
3.		
Average Time		*Average Speed*

Figure 8 • 20.

INTERPRETATIONS

4. Calculate the average speed of the large ball on the level track.
5. How do the results of Interpretations 3 and 4 compare with your prediction in Interpretation 2?

PROCEDURES

D. Use the timer to find how long it takes the small steel ball to change its speed from zero (at release) to the average speed it had on the level track. (Measure the time for the ball to roll from the point of release to the bottom of the inclined track.)

E. Repeat Procedure D using the large steel ball.

INTERPRETATIONS

6. *Acceleration* is any change in speed. (A decrease in speed is negative acceleration and is usually called *deceleration.*) To measure acceleration—that is, how rapidly speed is changed—we must know the speed at the beginning and at the end of the trial and the period of time involved. We can express this as a formula:

$$\text{Acceleration} = \frac{\text{change in speed}}{\text{time to produce the change}}$$

or

$$\text{Acceleration} = \frac{\text{final speed minus initial speed}}{\text{amount of time the speed was changing}}$$

Calculate the acceleration of the large steel ball and the acceleration of the small steel ball.

INVESTIGATION 8.7: Motion and the Force of Gravity

(pages 201–203)

Students should find that acceleration due to gravity has the same value for light objects as for heavy ones. The calculations are not too difficult, but they are secondary in importance to the concept of gravitational acceleration. If students can see that the heavy ball and the light one, released from the same height, require the same time to roll a given distance on the level track, they can understand the main concept without doing any mathematics.

MATERIALS

The block of wood should be about an inch thick. (The other dimensions are not critical.) Each section of grooved track should be about a half meter (20 inches) long.

If two sizes of steel balls are not available, you can use a marble in place of the smaller steel ball. However, a coating of aluminum oxide will offer more frictional resistance to a glass marble than to a steel ball. Thus, if the marble and the ball roll onto a level aluminum track at the same speed, the marble will slow down more than the steel ball—and will have a lower *average* speed. Since it is average speed the students calculate, such an effect could easily confuse them. This difficulty could be overcome by painting a track made of aluminum.

PROCEDURES

A. No comment.

INTERPRETATIONS

1. Sample data for Procedure A:

$$\frac{\text{Change in length due to large steel ball}}{\text{Change in length due to small steel ball}} = \frac{0.30 \text{ cm}}{0.12 \text{ cm}} = 2.5$$

   The force of gravity on the large steel ball is 2.5 times greater than the force of gravity on the small steel ball.
2. The less sophisticated student will probably guess that the heavier object will speed up more rapidly. Other students may realize that gravity accelerates all objects at the same rate. The underlying problem is to make the students fully aware of the implications of Newton's second law of motion ($F = ma$). No single investigation can be expected to accomplish this. In fact, one goal of this entire section is to help the students understand the meaning of the formula $F = ma$.

PROCEDURES

B. It is important that both the large and the small steel ball be released from the same point on the inclined track. The point should be high enough to give the ball a speed of about 15 cm per second on the level track. The timer should be set at about 4 clicks per second. Students should not hold the steel ball at the release point with their fingers; this may cause spin, which will influence the speed of the ball on the level track.

INTERPRETATIONS

3. Divide 40 cm by the number of timer clicks heard while the ball was rolling that distance on the level track. This will be an average value. Since it is an estimate, it will include some experimental errors, because the ball may not reach the level portion of the track at the same instant the timer clicks.

   Sample calculation:

$$\text{Speed} = \frac{40 \text{ cm (length of level track)}}{8 \text{ clicks (while ball was on } \textit{level} \text{ track)}}$$

$$\text{Speed} = 5 \text{ cm/click}$$

PROCEDURES

C. Check the tracks in advance to be sure that the large and the small steel ball actually do acquire the same speed in rolling down the incline and that the effect of friction with the track is the same for both objects.

INTERPRETATIONS

4. The calculated speed of the large steel ball should be the same as the speed of the small one (allowing for experimental error).
5. Since the gravitational force on the large steel ball is greater than the force on the small one, some students might suggest that there is another factor involved in the relationship between force and acceleration. This other factor, mass, will be studied in Investigation 8.9 and should not be explored at this time.

PROCEDURES

D. At the instant the ball begins to roll, its speed is zero. When it reaches the level track, its speed stops increasing. The increase in speed takes place entirely on the inclined track. Since the student is asked to find out how *rapidly* the speed of the marble changes, he must determine the time during which the speed of the ball in-

creases—in other words, the time the ball is on the inclined track.

E. No comment.

INTERPRETATIONS

6. Sample calculations:

Final speed = 5 cm/click; initial speed = 0.

$$\text{Acceleration} = \frac{\text{final speed} - (\text{minus})\ \text{initial speed}}{\text{time speed was changing}} = \frac{5\ \text{cm/click}}{4\ \text{clicks}}$$

Acceleration = $1\frac{1}{4}$ cm/click/click.

If students clearly understand that acceleration is a measure of how fast speed is changing, the next investigation will be much easier for them to carry out.

Acceleration

If you stop a bicycle at the top of a hill and then start coasting down the hill, you will experience a constant increase in speed. This might make you want to slow down by using the brakes. When you are on the hill, gravity can cause your speed to increase or decrease; friction can cause it to decrease.

A ball rolled up a hill does not move at a steady speed and then suddenly stop. It will gradually slow down, stop, and then start rolling back down the hill. Lacking brakes, the ball will continue increasing in speed until it reaches the bottom or until something stops it.

It is difficult to determine the speed of a ball rolling down a hill at any *one instant* of time. In the next investigation, you will attempt to determine the average speed of a ball for different intervals of time, while it is on the slope. From these averages, you can determine the acceleration of the ball.

INVESTIGATION 8.8: Measuring Changing Speed

Study the directions carefully before beginning the investigation. Your results can be accurate only if each person on your team does his job carefully.

MATERIALS (per team)

- Track
- Marking guide (card with a small hole in it)
- Masking tape
- Strip of paper (as long as the track)
- Steel ball or marble
- Timer
- Metric ruler
- Graph paper

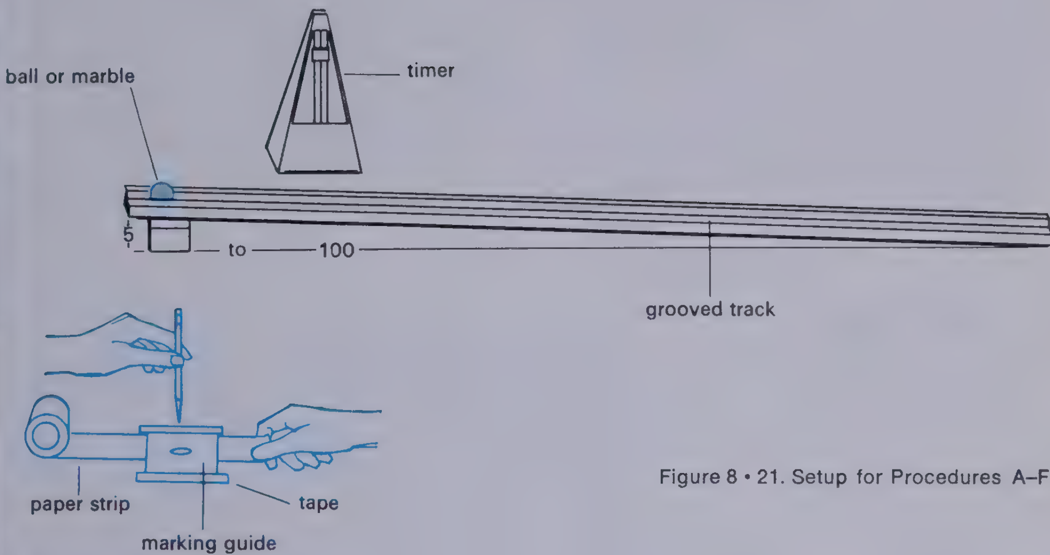


Figure 8 • 21. Setup for Procedures A–F.

PROCEDURES

A. Set the track at a slope of about 5 to 100 (Figure 8 • 18).

B. Tape the marking guide to the table near the raised end of the track, as shown in Figure 8 • 21. Slide the strip of paper under the marking guide.

C. Have one member of your team put the ball at the top of the track and hold it in position with a pencil. Have another team member grasp the end of the strip of paper and move it until it is even with the ball. Start the timer and release the ball at the instant the timer clicks. Practice sliding the strip of paper along the table so that its end stays even with the ball rolling down the track.

D. Now have another team member practice marking the moving paper strip through the hole in the marking guide. Use a ball-point pen and practice tapping the strip in time with each click of the timer.

E. When you have practiced enough to make your results dependable, turn over the paper strip and move it into starting position. Have the marker begin tapping the paper through

the hole in time with the clicks. This will mark the beginning point for your record. When the ball is released and the strip of paper is pulled, the marks on the paper will be separated by the distance the ball has moved between clicks.

F. Measure and record the distances between marks.

INTERPRETATIONS

1. Since the time interval for each distance you measured is 1 click, the average speed for that interval is numerically equal to the distance.

$$\text{Average speed} = \frac{\text{distance between marks}}{\text{1 click}}$$

   In your notebook, record the average speed for each time interval carefully.

2. Prepare a graph of your data. Plot the average speeds on the vertical axis and the time intervals on the horizontal axis.
3. Study the graph. Does the speed increase by the same amount from one time interval to the next?
4. If the amount of change from one time interval to the next is relatively constant, what is the average change in speed per time interval? What is the acceleration?
5. Compare your graph with the graphs prepared by other teams. Describe and explain any similarities and differences.
6. If the slope was increased, what would be the effect on the acceleration?

The Indianapolis 500 race

Snow geese on their annual migration

Speed and Acceleration

Figure 8 • 22. Some objects in motion. Which photo (or photos) shows constant speed? Which shows constant acceleration? Which shows speed, acceleration, and some deceleration (slowing down)?

Drag racing

INVESTIGATION 8.8: Measuring Changing Speed

(pages 204–206)

In this investigation the slope of the track remains constant; therefore acceleration should be constant. Although students may have *experienced* constant acceleration, this may be their first chance to analyze the experience.

Stress the importance of teamwork and the necessity for a careful study of the procedure before students begin work in this investigation.

PROCEDURES

A. An exact 5:100 slope may be difficult to establish. Any close approximation of this ratio will be satisfactory. The track should be at least 3 feet long and preferably longer. A sheet metal curtain rod makes a good track. Adding-machine tape is ideal for the marking strip.

B. The marking guide should be an index card with a small rectangular hole cut in it. Fasten the index card to the tabletop with masking tape.

C. No comment.

D. No comment.

E. Students should repeat the experiment several times to get an average.

F. A sample strip appears in Figure T-8 • 11.

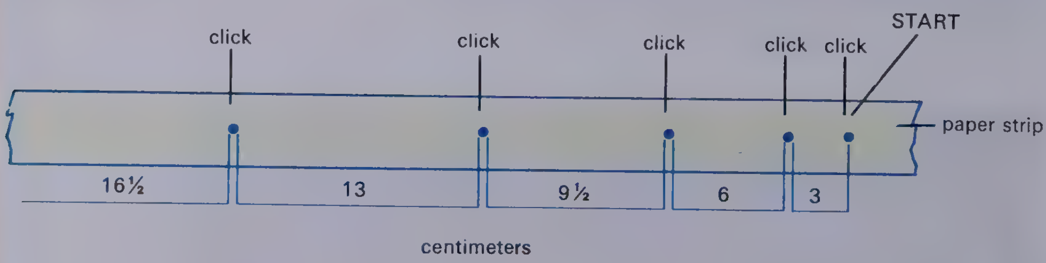


Figure T-8 • 11. Strip is moved from left to right.

INTERPRETATIONS

1. Average speeds are shown in Figure T-8 • 12.
2. The graph in Figure T-8 • 13 is based upon the data given in Figure T-8 • 12.
3. The increase in speed is relatively constant.

1.

Time Interval	*1*	*2*	*3*	*4*	*5*
Average speed	3 cm per click	6 cm per click	9½ cm per click	13 cm per click	16½ cm per click

Figure T-8 • 12.

NOTE: Speed = $\frac{\text{distance}}{\text{time}}$

Time remains constant: 1 click per unit of distance.

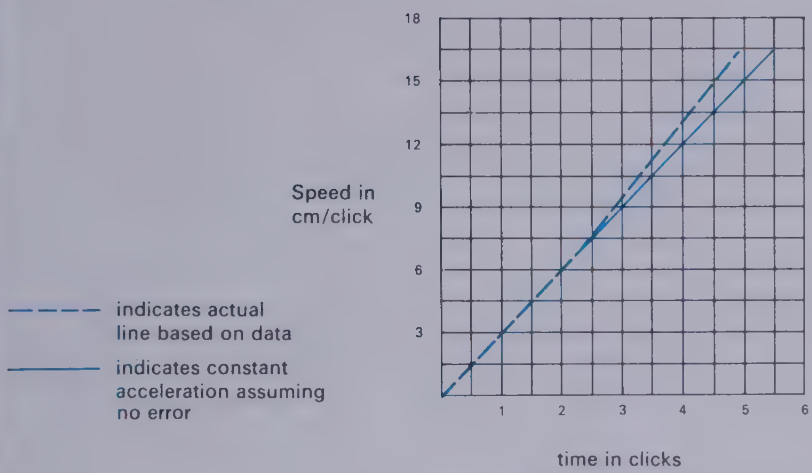


Figure T-8 • 13.

4. In the example cited, the average change in speed per unit of time is 3 cm/click/click. This value also represents the acceleration.
5. It is difficult to anticipate possible student responses.
6. If the slope was increased, acceleration would increase.

INQUIRY DEMONSTRATION: The Force of Gravity

(Teacher Only)

PART I: GRAVITY—A CONTINUOUS FORCE

Students have had a limited opportunity to investigate the acceleration of gravity. To provide them with evidence that gravity acts continuously and uniformly, show your students an example of projectile motion. Use a stream of water to illustrate the path of a projectile.

With rubber tubing connect a short section of glass tubing narrowed at one end (a medicine dropper tube will do) to a faucet. A 2-lb. coffee can with a small hole in the side, near the bottom, may be used in place of the faucet and tubing. Direct a stream of water horizontally so that the water falls into a sink or bucket. The path of the water shows that gravity continually changes the direction of fall until the path is vertical.

After students have observed the path of falling water, ask them to sketch the path followed if gravity pulled on a stream of water only part of the time—every other tenth of a second, for example.

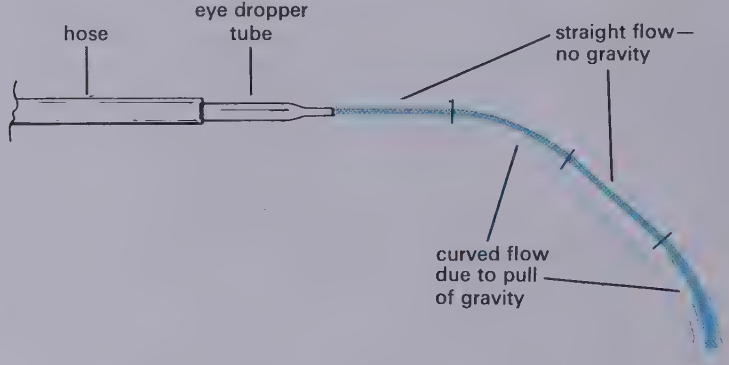


Figure T-8 • 14. Acceptable sketch showing theoretical effect of interrupted gravity on a stream of water.

PART II: GRAVITY—A UNIFORM FORCE

Construct a device similar to the one illustrated in Figure T-8 • 15.

MATERIALS

- Demonstration device
- Timer
- Steel ball

Tilt the guide so that the marble will roll along its surface. Start the timer and release the steel ball from the higher end of the guide. Have students count the number of clicks that occur before the ball strikes the bottom. Repeat until there is general agreement. Then roll the ball along the guide slowly and have the students count the number of clicks that occur before the ball strikes the bottom. Repeat until there is general agreement.

Roll the ball along the guide rapidly (but not so fast that it rolls off the far edge of the board instead of striking the bottom). Again have the students count the number of clicks that occur before the ball strikes the bottom of the board.

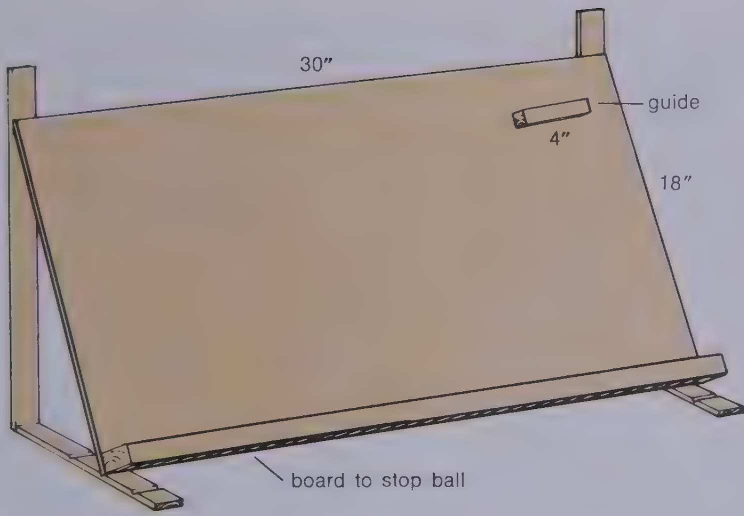


Figure T-8 • 15. Demonstration device.

The same number of clicks should be required for each trial. The only way to change the number of clicks is to change the slope of the large board. You may want to increase the slope and then repeat the demonstration.

If you would like to record the path of the ball to show its similarity to the path of water in the previous part of the demonstration, it may be done in any of the following ways:

1. Cover the face of the board with paper and place carbon paper face down on top of the paper. As the ball rolls, a light tracing of its path will be transferred from the carbon paper to the white paper.
2. Rub the board with a chalkboard eraser. The path of the ball will show as a faint track in the chalk dust.
3. Cover the board with construction paper and dip the ball in water before rolling it.

Figure 8 • 22. Speed and Acceleration

(page 207)

Most migratory birds fly at a constant speed except at takeoff or landing. In a drag race the cars are continuously accelerating. The track must be straight and not too long. A longer race, on an oval track, would necessarily involve both acceleration and deceleration, as well as some periods of constant speed.

Figure 8 • 23. An American astronaut on a space walk. Does he have weight?

INVESTIGATION 8.9: Mass

You have been told that an object in a capsule orbiting the earth is "weightless." This does not mean that such an object loses any of the matter it contains on earth, where it has weight. All the atoms that are part of the object when it is on earth are still there.

However, because the object is in orbit, it can no longer be weighed in the normal fashion. In fact, because of the rotation of the earth, an object has a different weight at the North Pole than it does at the equator. It is not the object that changes; it is the interaction between the object and the earth. There is something that is characteristic of the object no matter where it is; and that something we call *mass*. The mass of an object is a measure of the number and kinds of atoms that make it up. (Remember that an

atom of gold has more protons, neutrons, and electrons in it than an atom of hydrogen.) Mass is what determines the resistance of an object to changes of motion. And it is the number and kinds of atoms in the object that determines the degree of attraction between it and the earth. The distinction between mass and weight is that mass is a property of an object, while weight is a measure of the force with which the earth attracts the object. A few million miles away from the earth, the weight of any object would be almost zero, but its mass would remain constant.

MATERIALS (per team)

- Cart
- Pulley
- Objects of various masses
- Balance
- Weight
- Meterstick
- String
- Masking tape

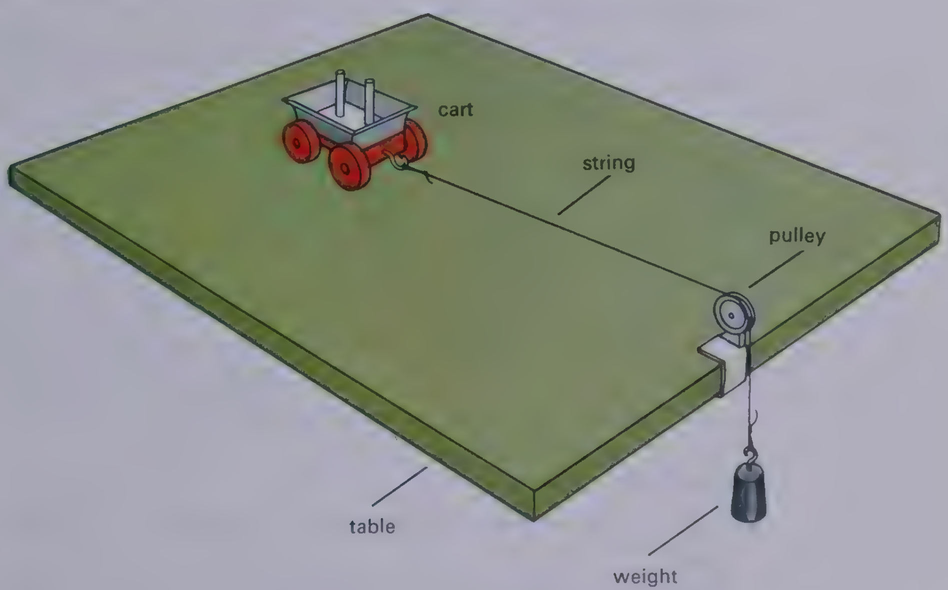


Figure 8 • 24. Setup for Procedures B–G.

PROCEDURES

A. Use the balance to find the *mass* (in this case, a more correct term than *weight*) of the cart in grams. Record the mass of the cart in your notebook.

B. Attach the pulley to the edge of the desk. Tie one end of the string to the weight and the other end to the cart. Place the string over the pulley and test to see that the cart rolls freely when pulled by the weight. See Figure 8 • 24.

C. Move the cart away from the edge of the table until there is no slack in the string and the weight is still on the floor. On the tabletop, mark the location of the front wheels with a piece of masking tape labeled *stop*. Label another piece of masking tape *start*. Place it 50 cm farther along the tabletop.

D. Pull the cart back to the start position. Use the timer to find out how many clicks are required for the cart to travel 50 cm when it is pulled from rest by the weight. Repeat this procedure two or three times and record the results in your notebook each time.

INTERPRETATIONS

1. What is the *average speed* of the cart for the trials in Procedure D?

PROCEDURES

E. Add enough additional mass to the cart so that its mass is double the number of grams for the empty cart. Record the total mass in your notebook.

F. Pull the cart back to the start position. Use the timer to find out how many clicks are required for the cart to travel 50 cm when it is pulled from rest by the weight. Repeat this procedure several times and record the results in your notebook.

INTERPRETATIONS

2. What is the *average speed* of the cart for the trials in Procedure F?
3. Explain why the answer to Interpretation 1 may be different from the answer to Interpretation 2.

4. Predict what would happen to the average speed of the cart if the total mass is made larger than the mass used in Procedure F.

PROCEDURES

G. Test your answer to Interpretation 4.

ON YOUR OWN: Two More Questions

What would be the effect of changing the distance the cart rolls? Of changing the amount of weight hanging on the string? Design and carry out investigations to answer these questions.

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INVESTIGATION 8.9: Mass

(pages 208–211)

In this investigation, smaller masses acquire speed more rapidly, yet all receive the same amount of pull from the suspended weight. The most reasonable explanation is that for some reason smaller amounts of material offer less resistance to a change in state of motion (moving or stationary). The weight of an object does not change very much from place to place, and we find it convenient to use weight as a measure of the mass of an object. But if the earth were more egg shaped, and we wished to compare the masses of objects at different latitudes, we would have to determine mass by methods like the ones used in this investigation.

MATERIALS

Any small cart or toy car will work well if the wheels spin freely. The cart should be capable of holding at least enough material to triple its own mass.

If commercial weight sets are not available, fishing weights or small bags of nails or any other common material can be used for the extra masses. Each team should have enough objects to double and triple the mass of the cart. The string should be at least 50 cm longer than the distance from the tabletop to the floor.

If a pulley is not available, the string can be allowed to run over the smooth edge of a table. Although it is not essential, if silicone spray is applied to the edge of the table, friction will be markedly decreased.

A sample apparatus should be tested to find the suitable amount of weight to hang on the end of the string. The empty cart should be pulled from rest, a distance of 50 cm in about 1 second.

A metronome timer adjusted to about 4 clicks per second will provide a time standard for the entire class.

PROCEDURES

A. The actual value for mass depends on the carts available. For the sample data, the mass was 200 g.

B. It is desirable to have enough weight tied to the string so that the empty cart, starting from rest, travels 50 cm in about 1 second. You will probably want to determine the proper amount of weight before assigning this investigation to the students.

C. No comment.

D. Sample data: number of clicks: 4,4,4,4.

INTERPRETATIONS

1. Sample data: the average speed is $\frac{50\text{ cm}}{4\text{ clicks}}$, or 12.5 cm/click.

PROCEDURES

E. Sample data: total mass = 400 g.
F. Sample data: number of clicks: 8,7,8,9.

INTERPRETATIONS

2. Sample data: the average speed is $\frac{50\text{ cm}}{8\text{ clicks}}$, or 6.25 cm/click.
3. The greater the mass, the harder it is to change its speed.
4. Students should predict that a greater mass would take even longer to travel 50 cm.

PROCEDURES

G. The time required will be longer than for Procedure F.

ON YOUR OWN: Two More Questions

(page 211)

If the same weight is tied to the end of the string, increasing the distance will increase the time.

If the distance is not changed, increasing the weight will decrease the time. Students should be reminded that good experimental design requires that they change only one variable at a time.

SUPPLEMENTARY MATERIALS

REFERENCES

Beiser, Germaine, and Beiser, Arthur. *The Story of Gravity: An Historical Approach to the Study of the Force That Holds the Universe Together.* New York: Dutton, 1968.

Bonner, Francis; Phillips, Melba; and Raymond, Jane. *Principles of Physical Science.* 2d ed. Reading, Mass.: Addison-Wesley Publishing Co., 1971.

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Rogers, Eric. *Physics for the Inquiring Mind.* Princeton, N.J.: Princeton University Press, 1960.
Valens, Evans G., and Abbot, Bernice. *The Attractive Universe: Gravity and the Shape of Space.* Cleveland: World, 1969.

FILMS

Forces. Encyclopaedia Britannica Film #1892. 14 minutes. Color. Show after Investigation 8.5. This film helps to illustrate the activities on force.

What Is Uniform Motion? Encyclopaedia Britannica Film #1868. 14 minutes. Color. Show after completing Investigation 8.8. The film helps to define motion, velocity, friction, force, gravity, and mass.

FILM LOOP

The Nature of Falling Bodies. Interaction Film Loops, Inquiry in Physical Science. Chicago: Rand McNally & Co., 1972.

SUGGESTED ACTIVITIES FOR TESTING LABORATORY SKILLS AND TECHNIQUES

INVESTIGATION 8.2

Use a force mechanism to launch a ball in a grooved track.

ON YOUR OWN: Inventing a Timing Device

Use a timing device (not a watch or clock) to time an event.

INVESTIGATION 8.5

Construct a spring-type force gauge.

INVESTIGATION 8.5

Using a force gauge, weigh an object.

INVESTIGATION 8.6

Use a force gauge to measure frictional force.

INVESTIGATION 8.7

Compute the speed of a ball rolling in a grooved track, with time and distance known.

INVESTIGATION 8.7

Compute the speed of a ball rolling in a grooved track, with time and distance measured by students.

INVESTIGATION 8.8

Mark equal time intervals on a strip of paper.

INVESTIGATION 8.8

Using a meterstick and the marks on a strip of paper, measure distance and time intervals.

SECTION NINE

Motion and Energy

SECTION NINE

Motion and Energy

(pages 213–238)

Preview

In this section students investigate the concept of momentum and develop from data the differences which exist between momentum and energy, even though both are derived from the mass and velocity of moving objects. The energy of motion (kinetic energy) is studied next, and students have an opportunity to further develop their model for motion. From interpretations of data, they express kinetic energy mathematically as MV^2. While $\frac{1}{2} MV^2$ is considered to be the correct formula for kinetic energy, the student's data is not precise enough to arrive at this. (MV^2 is both a reasonable and useful formula.) Next students study the conversion of potential energy to the energy of motion both with a speed track and with a pendulum. During the study of the pendulum, students discover the factors controlling the behavior of a pendulum by using different weights, changing its length, and varying its path.

The teacher's edition contains information for the interested student to determine the acceleration of gravity by using a pendulum. Another investigation is included as an "On Your Own" investigation (page 229) and is designed to give students a chance to explain a baffling problem.

LEARNING OBJECTIVES

Given the opportunity to inquire, to investigate, to interpret data, and to offer hypotheses about the activities in this section, most students should be able to—

- recognize motion as an indication of energy;
- describe and calculate the transfer of momentum in collisions of moving objects;
- analyze and interpret data to determine the relationship that exists between mass and velocity of a moving object;

- recognize and apply the concept of conservation of momentum to everyday examples (bowling, automobile collisions, skating, rolling logs, or riding a bicycle);
- demonstrate and explain the difference between momentum and energy;
- describe the conversion of potential energy to kinetic energy;
- recognize sources of experimental and procedural errors in the investigations on the motion of objects;
- recognize the variable factors that determine the period of a pendulum;
- demonstrate curiosity and critical thinking as they recognize examples of energy;
- incorporate the concept of the conservation of momentum into their evolving model for matter and energy.

Cro-Magnon man must have observed many of the same forces and effects in nature that we see today. But what kind of model did he use to explain what he observed? We have no way of knowing, but we can guess that fear and superstition may have been the main ingredients of his thoughts and beliefs. Primitive man knew lightning, thunder, tornadoes, raging forest fires, earthquakes, and other natural phenomena. His own feelings of fear and awe were probably the only bases he had for constructing models.

Just for convenience, imagine that Cro-Magnon man used the word *energy* to refer to the cause or power in natural events. He might then have classified energy according to the different events observed: wind energy, lightning energy, thunder energy, rain energy, sun energy, fire energy, and so forth. A modern model distinguishes between different kinds of energy—but not on the same basis supposedly used by our Cro-Magnon thinker.

We know that our surroundings are continuously changing. Our planet rotates on its axis as it moves around the sun. As a result, we have night and day. And because the earth's axis is "tilted," we have the changes known as seasons. Some days are clear and sunny. Others are cloudy and rainy. Sometimes the wind blows, and at other times it does not. Some days are hot. Others are cold. Most of these variables result from changes in kinds or amounts of energy. A modern model of energy takes into account our knowledge that all matter, from the largest star to the smallest particle of an atom, contains stored energy. Under certain conditions, the energy is released to produce observable changes.

We have already used the term *energy* in referring to heat given off during certain chemical reactions. We have not yet explored the meaning of energy. Energy itself is not visible. But we can often observe the effects of energy on matter. As you investigate different kinds of energy, keep in mind that no matter how unlike their effects may be, different kinds of energy may be related. Cro-Magnon man probably saw no relationship between lightning and the warmth from his own fire. In what way do you think fire and lightning might be related?

Figure 9 • 1. Cro-Magnon people observing a tornado. What kind of model do you think these people might have used to explain this force of nature?

Your energy comes from the food you eat. You might use some of this energy to roll a ball. What happens to the energy after you release the ball? The energy is transferred to the ball, and its effect can be observed as motion. But the amount of energy of motion can be determined only if you know the mass and speed of the ball. You will calculate energy of motion of some objects in this section.

In your investigations with bluestone, you changed heat energy into chemical energy. Energy can be changed from one form to another, but never created or destroyed. This concept is called the *Principle of Conservation of Energy.*

You will be asked to develop a model that will give you a better understanding of what *energy* really means. Use your own insight and prior knowledge, as well as the results of investigation, to develop the model. You will not necessarily reach the goal, for it is a difficult one.

At this point we hope you will think carefully about the investigations you have performed and the models you have constructed. You should be prepared to relate these experiences to the investigations in the following sections.

PROBLEMS

1. List all the kinds of energy you think may exist (much as our imaginary Cro-Magnon man might have done in a more limited way).
2. Find out and report on possible causes of lightning and thunder and how the two are related.
3. Try to find historical accounts of tornadoes, typhoons, volcanic eruptions, and earthquakes. How have man's explanations of these natural events changed through history?
4. What scientific ideas are used in modern attempts to cause rainfall? What are some other examples of man's efforts to alter or control weather and climate?

Figure 9 • 2. What force could produce the amount of energy necessary to cause damage to the extent shown here?

Motion and Energy

(pages 214–216)

The terms *momentum* and *energy* represent two distinct concepts. The investigations in this section are intended to show how these concepts are related and why both are needed to describe motion. Students should discover how momentum and energy are related to their model of the structure of matter. They should also observe that both momentum and energy are conserved when objects collide.

Through class discussion, attempt to find out how well students understand the use of a model in science. Do they understand the nature of scientific "truth"? Can they accept science as a creative activity that leads to ever-expanding knowledge of our environment? Are students able to distinguish between sound information and dogmatic statements—between observation and interpretation?

For Figure 9 • 1 any reasonable model explaining the existence of tornadoes should be accepted. For example, primitive men might have thought tornadoes were caused by their own deeds, by the actions of enemies, or by supernatural beings.

For Figure 9 • 2 possible answers for the source of energy include a tornado, an explosion, or a flood.

PROBLEMS

1. This should be performed as an in-class activity without the aid of reference materials or an opportunity to read ahead in the text. A comparison of reports could form the basis for a lively discussion.

2.–4. These are designed for out-of-class study. Encourage the use of reference materials. Point out that use of relevant literature is an important part of a scientist's work. Failure to read about what others have done may lead a scientist to duplicate effort or produce work that is obsolete or incomplete.

Each problem has several topics. You may wish to assign different topics to members of each team or have each team prepare a cooperative report on a problem. Problem 4 lends itself to a discussion of small-scale attempts to control climate, such as air conditioning, central heating, humidifying, and so forth.

The Meaning of Momentum

Momentum is a word that may be used to describe motion. Perhaps you know that a heavily loaded truck has more momentum than a sports car traveling at the same speed. A clear understanding of momentum will be useful and important in the study of motion and energy.

All moving objects have momentum, whether they are as large as the earth or as small as an atom. Studying the behavior of marbles may provide information that will be useful in improving your atomic model.

Objects have momentum only when they are in motion. Momentum is calculated by multiplying the mass of an object by the speed of the object.

$$M = mv$$
$$(M = \text{momentum};\quad m = \text{mass};\quad v = \text{speed})$$

(The v is taken from the word *velocity*, which has a meaning slightly different from that of *speed*. A definition of velocity includes both the speed and direction of motion. We will continue to use the term *speed*, however, because for our purposes it has much the same meaning as velocity.)

A cart weighing 20 grams and traveling at a constant speed of 5 centimeters per second has a momentum equal to the momentum of a 10-gram cart traveling at a constant speed of 10 centimeters per second.

Note that the momentum of the first cart is equal to the momentum of the second cart.

Cart 1: M = 20 grams x 5 cm/sec. = 100 gram cm/sec.
Cart 2: M = 10 grams x 10 cm/sec. = 100 gram cm/sec.

It is not important for you to remember that the units for momentum may be gram centimeters/second. The units were mentioned to emphasize the conditions that must exist if you are going to compare momentum for two objects. The momentum of

one object cannot be compared to the momentum of another unless both masses are measured in the same kind of units (for example, grams) and both speeds are measured in the same kind of units (for example, centimeters/second).

What would happen if a marble weighing 10 grams and traveling at a speed of 5 centimeters/second struck a 10-gram marble that was not moving? This and other problems dealing with momentum will be the focus of Investigation 9.1.

INVESTIGATION 9.1: Analysis of Momentum

Momentum is something that changes the lives of thousands of people every year, often with tragic results. If more people understood its meaning, they might use this knowledge to their benefit.

MATERIALS (per team)

Track with force mechanism
Marbles (of the same weight), 8
Steel balls, 2

PROCEDURES

A. Make sure the track is level. Place a marble in the groove about 5 cm from the launching point. Launch a second marble with a measured amount of force. Record the setting used on the force mechanism and the reaction that occurs between the two marbles.
B. Place five marbles in the middle of the grooved track so that they touch each other. Launch a marble with the same force setting used in Procedure A. Then record the effect on the five marbles.
C. Place five marbles in the middle of the grooved track as in Procedure B. Shoot two marbles at the same time and with the

same force setting used before. Record the effect on the five marbles. Repeat this procedure shooting three marbles at the same time and record the effect on the other five.

D. Place a marble in the middle of the grooved track. Shoot one of the steel balls with the same force setting. Then record your results.

INTERPRETATIONS

1. What happened to the momentum of the marbles launched in Procedures A, B, and C?
2. As a result of the collisions, how did the change in momentum of the steel ball in Procedure D compare with the change in momentum of the marbles that were launched in Procedures A, B, and C?
3. Carefully study the results of each procedure. Recall that momentum is a property of a moving object and is equal to the mass of an object times its speed. From the results of the experiments you have performed, state a general law about momentum.
4. From your observations, predict what will happen if a steel ball is placed in the middle of the track and a marble is launched at it. Record your prediction.

PROCEDURES

E. Place a steel ball in the middle of the track and launch a marble at it. Observe the direction of motion of each after the collision. Roughly compare the speed of the marble before and after the collision.

INTERPRETATIONS

5. What three factors seem to determine the results of the collisions you observed in Procedure E?
6. Suppose that an auto and a large, heavily laden truck are each traveling at 50 miles per hour. Which would have the greatest change in direction and speed if they were to collide head on? Base your answer on your previous investigation of the collision between a marble and a steel ball.

ON YOUR OWN: Predicting Directions

In the analysis of motion, it is not enough to know the speed of an object. You must also know the exact *direction* in which an object is moving. The combination of speed and direction is *velocity*. Can you predict what direction a steel ball will take after it collides with another steel ball?

As long as you limit the direction of motion with a track, it is fairly easy to predict the result of a collision.

Previously the directions in which the marbles and steel balls moved after collision were limited by the track. In this investigation, the steel balls will be free to move in any direction on a tabletop after they collide.

MATERIALS

Steel balls, 2
Carbon paper
Tracing paper
Pen and pencil

Place carbon paper on the table, carbon side up, and lay tracing paper over it. The weight of a steel ball will leave a track on the bottom of the tracing paper. Roll the steel balls toward each other —one from each hand. Try to release the balls in such a way that they have approximately equal speed. Make sketches of several collisions, using circles to represent the steel balls and arrows to indicate their movements. Use ink to draw the circle and arrow for one ball. Use pencil to draw the circle and arrow for the other ball.

INVESTIGATION 9.1: Analysis of Momentum

(pages 218–219)

Though momentum and energy of motion are two distinct concepts, both are calculated from the mass and velocity of a moving object. Momentum is defined as the product of mass and velocity. Energy of motion (often called kinetic energy) is equal to half the product of mass and the square of velocity ($\frac{1}{2} mv^2$). In this investigation students observe conservation of momentum. The procedures and the students' interpretations of the results should lead them to wonder what other concept is needed to explain the behavior of colliding objects.

Suppose that two marbles rolling in a groove strike some stationary marbles. Momentum is conserved if one marble rolls away from the far end of the stationary group at twice the speed of the first two marbles. Assuming that all the marbles have the same mass, the mass of one marble is half as great as the mass of two. Therefore if the speed of the single marble is twice the speed of the two marbles, momentum is conserved.

But marbles never behave that way. If stationary marbles are struck by two marbles, *two* marbles roll away from the other end. If three marbles strike the stationary marbles, *three* marbles roll away from the far end.

The purpose of this investigation is to provide an opportunity for students to analyze motion in terms of mass and velocity; learning how to solve complex equations is not an intended goal. This investigation should help students see that momentum is conserved and that the concept of momentum does not completely explain the results of collisions.

MATERIALS

Use the same track and force mechanism as in previous investigations. The size of the small marbles is not critical as long as they are all equal in weight. Steel ball bearings are ideal for the heavy balls. They should be about the same diameter as the marbles.

If necessary use a level so that the track is perfectly horizontal.

PROCEDURES

Use the same force setting in Procedures A through D. Before students begin this investigation, work through the procedures to determine the minimum force setting that will produce observable results in Procedures A through D.

A. When the collision occurs, the launched marble should come to rest. The velocity of the second marble should be approximately equal to the initial velocity of the launched marble.

When the marble is launched, it *slides* for a short distance, until friction with the track causes it to begin rotating (rolling). In this procedure the second marble should be struck while the launched marble is still sliding (not yet rolling). If the collision occurs after the launched marble has started rotating, the launched marble will begin rolling again after the collision—as a result of friction with the track. This effect may make it difficult for the students to observe the investigation properly. For this reason the second marble should be placed about 5 cm from the launching point of the first marble in Procedure A.

In the remaining procedures, the additional marbles offer enough inertia and friction to minimize this effect.

B. After the collision, one marble will roll away from the opposite end of the row. The launched marble will come to rest.

C. When two marbles are launched, two will roll away from the opposite end of the stationary row after the collision. When three marbles are launched, three will roll away after the collision. In both cases the launched marbles will come to rest.

D. The marble will roll down the track after the collision. The steel ball will continue rolling in the same direction, with a little less speed.

INTERPRETATIONS

1. The momentum of the marbles launched in Procedures A, B, and C was transferred to an equal number of stationary marbles.
2. Most of the momentum of the steel ball was not transferred to the marble. The steel ball continued rolling with only a little less momentum than it had initially.
3. Our intention is for students to "discover" *conservation of momentum.* They may not express the concept in these words, but they should be able to state that the momentum of the launched marble was transferred to one or more of the other marbles and that momentum is equal to the weight of the launched marble times its speed.

   The momentum of two objects with different masses cannot be equal unless the mass and velocity of two objects vary inversely. That is, if momentum is to remain constant, any increase in mass must be matched by a decrease in velocity; conversely, if velocity is increased, mass must be decreased. For example, a mass of 2 g

moving at a velocity of 10 cm/sec has a momentum equal to:

$$2\ g \times 10\ cm/sec = 20\ gcm/sec$$

If the mass is increased to 4 g and velocity decreased to 5 cm/sec, the momentum is:

$$4\ g \times 5\ cm/sec = 20\ gcm/sec$$

Thus a 100 g mass moving at a velocity of 1 cm/sec has the same momentum as a 1 g mass moving at a velocity of 100 cm/sec.

4. Students may make many different predictions, but it is unlikely they will make a correct one. This emphasizes the need for experimentation in science.

PROCEDURES

E. After the collision, the steel ball should roll away from the marble and the marble should recoil. It is difficult to estimate the recoil speed, but the speed of the steel ball is quite slow compared with the launching speed of the marble.

INTERPRETATIONS

5. The mass of each ball, the speed of the launched ball, and the friction with the track determine the results of the collisions.
6. The auto would have the greatest change in speed and direction. Students could cite Procedure E in support of this answer.

FOR FURTHER DISCUSSION

1. If two marbles rolling together in the same direction in a grooved track strike a row of stationary marbles, what will happen? (Two marbles will roll from the far end of the row.)
2. Compare the momentum of the two marbles that rolled after the collision with the momentum of the marbles that rolled before the collision. (They are equal.)
3. Assume all marbles have equal masses. If one marble rolled away after the collision at twice the speed of the two marbles that rolled before the collision, would momentum be conserved? (Yes.)
4. Again assume all marbles have equal masses. If four marbles were to roll away at half the speed the two marbles had before the collision, would momentum be conserved? (Yes.)
5. Since marbles cannot "decide" how to act, do you think that the concept of momentum is sufficient to explain the behavior of colliding objects? (No.)

The next investigation deals with energy of motion. Though the investigation does not involve collisions, it may help students to gain a better understanding of them.

ON YOUR OWN: Predicting Direction

(page 220)

The speed and direction of each ball after a collision is not predictable. Some collisions would cause one ball to move faster than the other; some collisions would cause both to move at about the same speed. The directions probably would be different each time.

Since direction depends on the angle of collision, great variability will be noted in the direction and amount of speed of each ball after it collides.

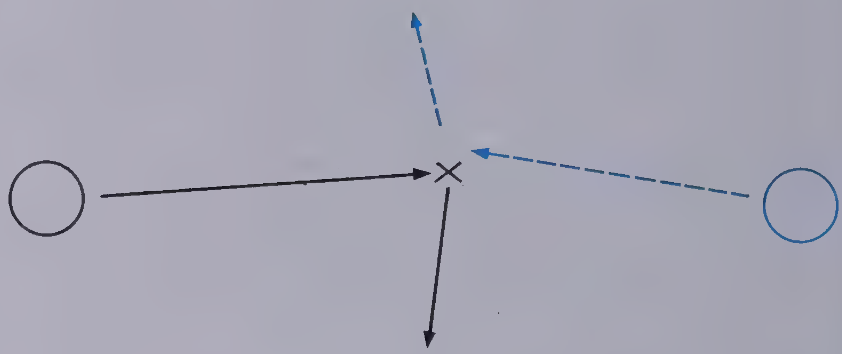


Figure T-9 • 1. Possible student sketch.

INVESTIGATION 9.2: Energy of Motion

You have seen that a rolling ball continues to move unless it is stopped by friction or by another object. The concept of momentum may be helpful in understanding motion, but it leaves some questions unanswered. For example, why is there a certain relationship between the number of marbles that strike a row of stationary marbles and the number that roll away?

During Investigation 8.9, you saw that the force of gravity can produce acceleration. But how is the change in speed related to gravity? When you lift a rock, gravity pulls down on it with a steady force. If you drop the rock from a height of 6 feet, it will be falling faster when it hits the ground than if you had dropped it from a height of only 1 foot. Every object has energy as a result of the pull of gravity. This energy is called *energy of position,* and it is changed into *energy of motion* if the object is allowed to fall.

Energy is stored up when you lift something and is released as the object falls. If you could measure the speed of a falling object at different points in its path, you could compare the distance it has fallen with the speed it has gained. It is not easy to measure the speed of a falling object. A marble rolling in an inclined track may provide us with an opportunity to compare the change in height with the speed produced. Data from this comparison then can be used to establish a relationship between energy of position and energy of motion.

MATERIALS (per team)

- Grooved track, 2 sections
- Tape
- Marbles, 2
- Steel balls, 2
- Timer
- Block of wood
- Strip of paper
- 3 x 5 index card

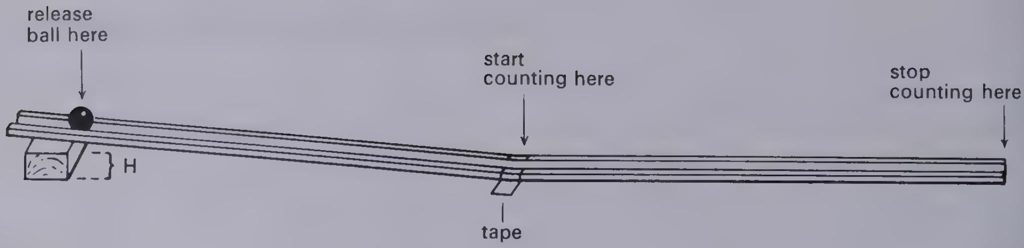


Figure 9 • 3. Setup for Procedures A and B.

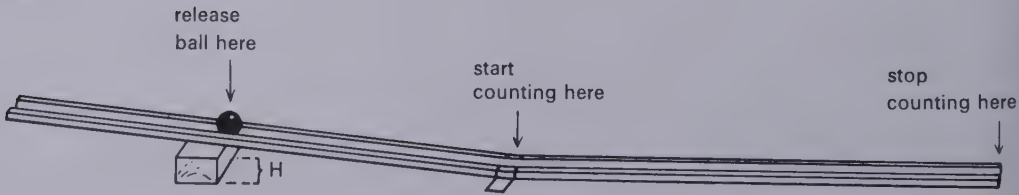
PROCEDURES

A. Place the two sections of grooved track together as shown in Figure 9 • 3 and fasten them with tape. Raise one end of the track and place the block under it—about 5 cm from the raised end. Be sure a steel ball or marble can roll smoothly from one section of the track to the other.

B. Put a steel ball on the track directly above the point supported by the block. Turn the timer on and release the ball. Start counting when the ball reaches the level section of track. Stop counting when it reaches the end of the level track. Measure and record the length of the level track. Record the time required for the ball to travel that distance.

C. Move the support block so that it is under the *middle* of the inclined track. Again place a steel ball on the track just above the point supported by the block. Release the ball and measure the time required for the ball to roll the length of the level track. Even though the incline is steeper, note that the ball will experience the same change in height as it did in Procedure B. Record the time required for the ball to travel the length of the level track.

Figure 9 • 4. Setup for Procedure C.



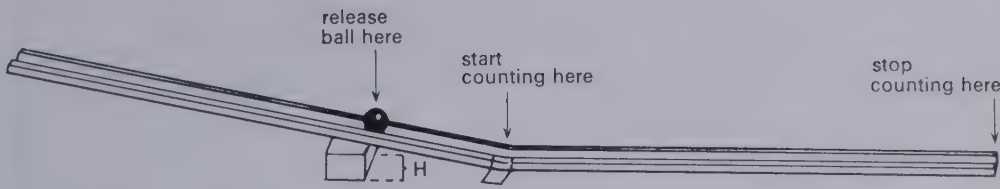


Figure 9 • 5.
Setup for
Interpretation 1.

INTERPRETATIONS

1. Calculate the speed of the ball on the level track in Procedures B and C. Move the support block to a point three-quarters down the length of the inclined track, as shown in Figure 9 • 5. Predict the amount of time the ball will take to travel the length of the level track. Record your prediction.

PROCEDURES

D. Test the prediction you made in Interpretation 1.

INTERPRETATIONS

2. What effect did changing the slope in Procedures C and D have on the speed of the ball on the level track?
3. In these trials, what was the relationship between the *height* from which the ball was released on the inclined track and the *speed* of the ball on the level track?

PROCEDURES

E. Return the support block to the midpoint of the inclined track. Fasten the strip of paper to the side of the inclined track. Hold a 3 x 5 card on edge next to the level track as shown in Figure 9 • 6. Place a mark on the card at the level of the track. Label this mark *0*.

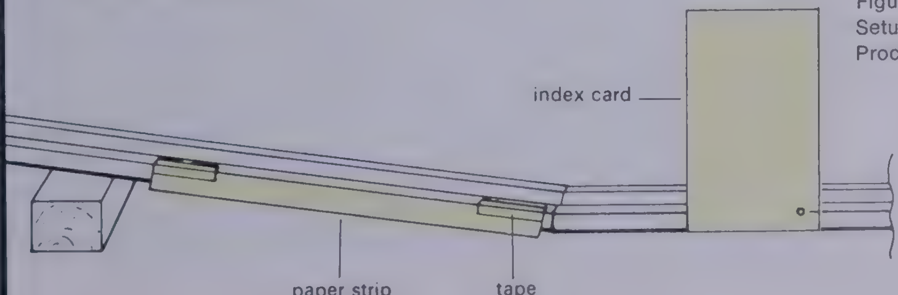


Figure 9 • 6.
Setup for
Procedure E.

Measuring up from zero, mark off and label the following distances on the card: 1 cm, 2 cm, 3 cm, 4 cm (Figure 9 • 7). Hold the card on the table in an upright position again and slide it along the inclined section of the track until the 1-cm mark on the card is just even with the top edge of the track. Be sure to hold the card straight so that the measurements of vertical distance are correct. Hold a sharp pencil against the edge of the card at this point and draw a vertical line on the paper strip attached to the inclined track. A ball released at this point on the track will fall 1 cm before it starts rolling on the level track. Use the index card to mark release points on the inclined track that are 2, 3, and 4 cm above the level track.

F. Place the ball at the 4-cm mark and release it. Record the time required for the ball to roll the length of the level track. Repeat several times and record the average of the trials.

G. Repeat Procedure F for each height marked.

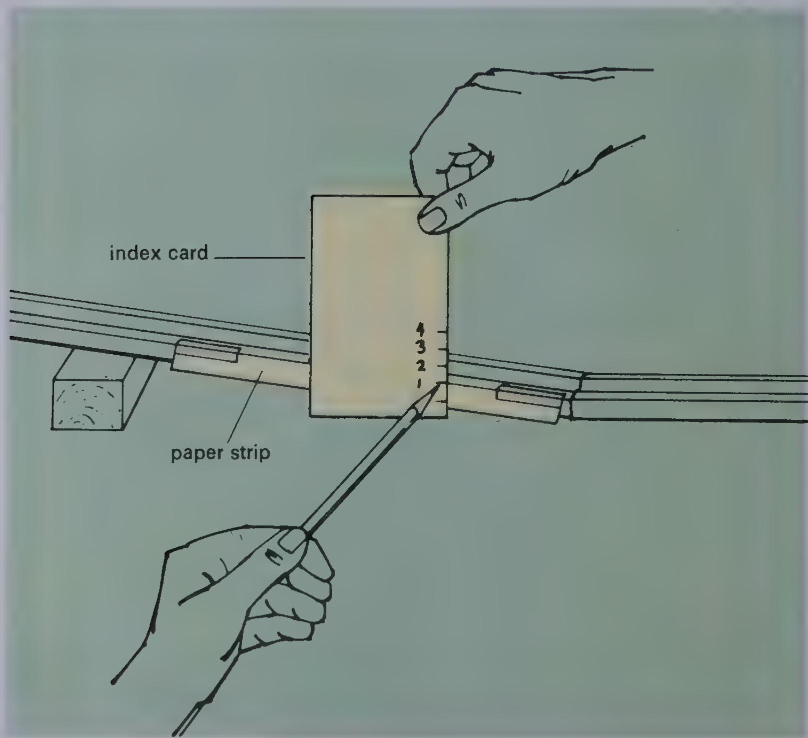


Figure 9 • 7. Carrying out Procedure E.

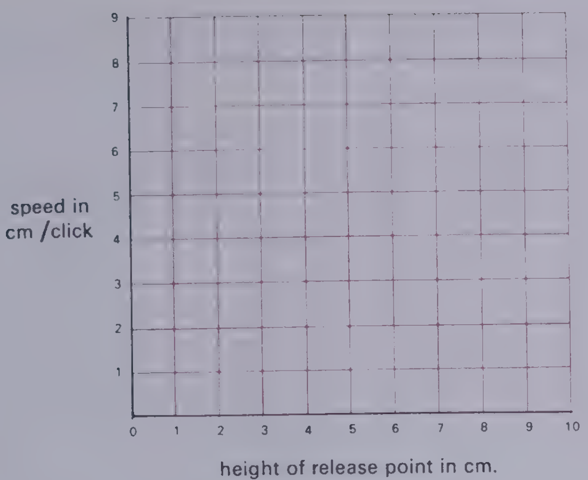


Figure 9 • 8.

INTERPRETATIONS

4. Calculate the average speed of the ball on the level track for each release point. Prepare a graph as shown in Figure 9 • 8. Plot the average speed for each release point.
5. If you double the height of the release point, does the ball roll twice as fast?
6. Calculate the values for the following ratios:

a. $\dfrac{\text{Speed from 2-cm height}}{\text{Speed from 1-cm height}} =$

b. $\dfrac{\text{Speed from 4-cm height}}{\text{Speed from 2-cm height}} =$

c. $\dfrac{\text{Speed from 4-cm height}}{\text{Speed from 1-cm height}} =$

Compare your calculations with those of other teams.

7. Suppose you want the ball to roll twice as fast on the level track as it did when you released it from the 2-cm mark. From what height should you release it?

NOTE: *Procedures H through N and Interpretations 8 through 14 are optional.*

PROCEDURES

H. Place a marble at the 4-cm mark on the inclined track. Release the marble. Measure and record the time required for the marble to roll the length of the level track.

INTERPRETATIONS

8. Calculate the speed of the marble on the level track.
9. Compare the speed gained by a marble in Procedure H with the speed gained by a steel ball in Procedure F.

PROCEDURES

I. Place a marble on the track where the two sections are joined. Place a steel ball at the 4-cm mark on the inclined track. Release the steel ball. Measure and record the time required for the *steel ball* to roll the length of the level track.

J. Repeat Procedure I, but replace the steel ball with a second marble. Measure and record the time required for *the marble you released* to roll the length of the level track. (It will be rolling behind the first marble.)

INTERPRETATIONS

10. Why was the measured time in Procedure I different from the measured time in Procedure J?

PROCEDURES

K. Use a balance to measure the mass of the steel ball and the mass of the marble. Record these masses.

INTERPRETATIONS

11. Calculate the momentum of the marble rolling on the level track after it has been released from a height of 4 cm.
12. *a.* For the steel ball to have a momentum equal to the momentum you calculated for the marble, what must be the speed of the steel ball?

b. Calculate the time required for the steel ball to roll the length of the level track if it has the speed determined in Interpretation 12*a*.

c. Use the graph you prepared in Interpretation 4 to determine the height from which the ball should be released if it is to have the speed calculated in Interpretation 12*a*.

PROCEDURES

L. Place the steel ball on the inclined track at the height you calculated in Interpretation 12*c*. Release the ball and determine the time required for it to roll the length of the level track. If the time required to roll the length of the level track is not the same as the time you calculated in Interpretation 12*b*, move the ball to a different position. Continue the trials until the calculated time and the observed time are the same. Record the height of the ball in the final position.

INTERPRETATIONS

13. Suppose that a rolling steel ball collides with a stationary steel ball. If a marble (rolling with the same momentum) collides with a stationary steel ball, would the rolling ball and the rolling marble behave in the same way? Record your prediction.

PROCEDURES

M. Place a steel ball on the track where the two sections join. Place the other steel ball at the position on the inclined track determined in Procedure L. Release the ball and record the result of the collision.

N. Place a steel ball on the track where the two sections join. Place a marble on the inclined track at the 4-cm mark. Release the marble and record the result of the collision.

INTERPRETATIONS

14. Since both the steel ball and the marble had the same momentum, how can you account for the results observed in Procedures M and N?

You have seen that energy of position (or gravitational energy) can be converted into energy of motion. Objects that fall through a particular distance always gain the same amount of speed, no matter how heavy they are.

Doubling the distance of fall does not double the speed. Doubling the distance of fall *does* double the energy of motion. Experiments have shown that the energy of motion of an object increases in direct proportion to the square of the speed. You have seen that the energy of motion is less for a heavy object than for a light object, if both have the same momentum.

Energy of motion is determined by multiplying the mass of an object by the square of its speed, or mv^2. In Section Eleven, you will study the relationship between energy of motion and heat energy. Both of these concepts must be included in a model that is useful in explaining the behavior of matter.

INVESTIGATION 9.2: Energy of Motion

(pages 221–228)

There is a difference between energy of motion as defined in this section and the definition of kinetic energy. Kinetic energy is equal to $\frac{1}{2}mv^2$. We have defined energy of motion as mv^2. The reason we use this definition is that students' data are not likely to be precise. Accurate measurements would show that the energy of a moving object is equal to $\frac{1}{2}mv^2$. We could assert that the factor $\frac{1}{2}$ should be included, but this only resorts to higher authority. It is desirable that students consider their own data the authority they are most willing to accept.

MATERIALS

The sections of grooved track should be at least 50 cm long and may be the same ones used in Investigation 9.1.

Students will need a balance to complete the optional part of the investigation.

One timer may be used for the entire class. It should be set at the highest rate that can be counted, since this will minimize error at the beginning and end of the timing process. The timing should begin when the ball rolls onto the level track and stop when the ball reaches the end of the track. Since it is unlikely that the ball will reach either of these points at the same instant the timer clicks, some error is almost inevitable. It is difficult to count clicks at a rate higher than 4 or 5 per second, but the highest rate at which students can count should be used.

The block of wood could be a piece of two-by-four.

In Procedure E, students should mark on the strip of paper—not on the track.

PROCEDURES

A. Test the level section of the track to see that the marble does not lose too much energy either at the junction with the inclined section (because of poor alignment) or along its length (because of friction or improper leveling). The former can be checked by ear: there should be no clicking sound when the ball moves from one section to the other. Friction and leveling can be checked by comparing the time required for a ball to travel over the first half of the level track with the time required for it to cover the second half.

B. The position of the block is not critical, but the height of the release point must be the same in Procedures B, C, and D. If the ball

is placed just above the forward edge of the block each time, then height will be constant—and equal to the height of the block plus the thickness of the track. For uniform results, it is probably best to have the student hold the ball in position with a pencil and release it by lifting the pencil.

C. When the block is moved forward, check the tape which joins the two sections together. It should have the same alignment as it does in Procedure A.

The time the ball takes to travel the length of the level track should be the same as in Procedure B.

INTERPRETATIONS

1. The speed is computed by dividing the number of clicks into the length of the level section of track. The student may predict that the time the ball takes to travel the length of the level track will be the same as in Procedures B and C.

PROCEDURES

D. The time should be the same as in Procedures B and C.

INTERPRETATIONS

2. The change in slope did not affect the speed of the ball on the level track.
3. The height of release was the same for all trials, and the speed on the level track was the same in every trial (allowing for experimental error).

PROCEDURES

E. It is easier and probably more accurate to use an index card or stiff paper to measure heights rather than a ruler. Be sure students understand why the thickness of the level track is used to establish the zero point—so that the *actual* change in height for the ball in traveling from a point on the inclined track to the level track is measured.

F. The data obtained by the students depends on the rate of the timer and the length of the track.

G. The time the ball takes to travel the length of the level track should increase as the height of the release point decreases.

INTERPRETATIONS

4. Typical data for a *50 cm* length of track are as follows:

Height of release point in cm:	1	2	3	4
Number of clicks:	8	6	5	4
Speed cm/click:	6.3	8.3	10.0	12.5

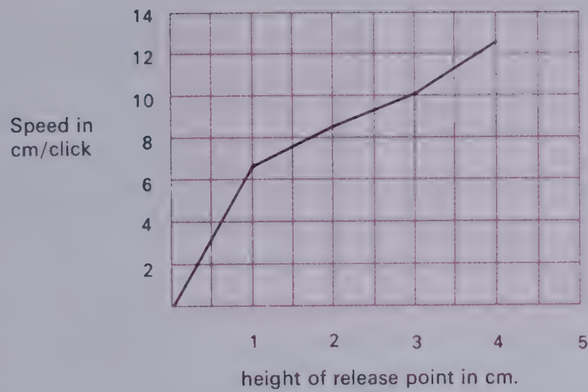


Figure T-9 • 2. Graph of typical data for Interpretation 4.

5. No, the ball does not double its speed when the height of the release is doubled.
6. The following values are calculated from sample data in Interpretation 4:

a. $$\frac{\text{Speed from 2-cm height}}{\text{Speed from 1-cm height}} = \frac{8.3 \text{ cm/click}}{6.3 \text{ cm/click}} = 1.3$$

b. $$\frac{\text{Speed from 4-cm height}}{\text{Speed from 2-cm height}} = \frac{12.5 \text{ cm/click}}{8.3 \text{ cm/click}} = 1.5$$

c. $$\frac{\text{Speed from 4-cm height}}{\text{Speed from 1-cm height}} = \frac{12.5 \text{ cm/click}}{6.3 \text{ cm/click}} = 2.0$$

   You may want to compare data from different teams on the board.
7. By referring to the calculation in Interpretation 6, students should see that to double the speed, the height would have to be four times as great. In other words, for the ball to roll twice as fast on the level track as it does when released from 2 cm, it would have to be released from 4 × 2 cm, or 8 cm, above the level track.

NOTE: *Procedures H through N and Interpretations 8 through 14 are optional.*

PROCEDURES

H. The time to travel the length of the level track should be the same for the marble as it was for the steel ball. Using a 50-cm length of track, with the timer set at about 5 clicks per second, the time should be 4 clicks.

INTERPRETATIONS

8. Sample data:

$$\frac{50 \text{ cm}}{4 \text{ clicks}} = 12.5 \text{ cm/click}$$

9. The speed gained by a marble should be the same as the speed gained by a steel ball when both are released from the same height.

PROCEDURES

I. The speed of the steel ball changes only slightly. In several trials, we found that the time the steel ball took to travel the length of the level track was about 5½ clicks.

J. The marble will come to a stop as a result of friction.

INTERPRETATIONS

10. Students are likely to say that the reason for the difference is that the steel ball is heavier. In discussion, bring out the idea that two objects moving at the same speed possess different amounts of energy if their masses are different.

    Ask students to express the relationship between energy of position and mass. In this investigation energy of motion comes from energy of position, so at the 4 cm height a steel ball has more energy of position than a marble does.

PROCEDURES

K. Typical data:

Mass of steel ball = 16.9 g

Mass of marble = 7.1 g

INTERPRETATIONS

11. Momentum is equal to mass times velocity. In the sample data the momentum of the marble on the level track would be 7.1 g $\times$ 12.5 cm/click, or 89 gcm/click.

12. From the sample data:

    a. Momentum = mass $\times$ velocity

    or

    $$89 \text{ cm/click} = 16.9 \text{ g} \times v$$

    $$v = \frac{89}{16.9} = 5.3 \text{ cm/click}$$

b. $$\text{Time} = \frac{\text{distance}}{\text{rate}}$$

$$\text{Time} = \frac{50\text{ cm}}{5.3\text{ cm/click}} = 9.5\ (9\tfrac{1}{2}\text{ clicks})$$

c. The graph should resemble that shown in Figure T-9 • 3.

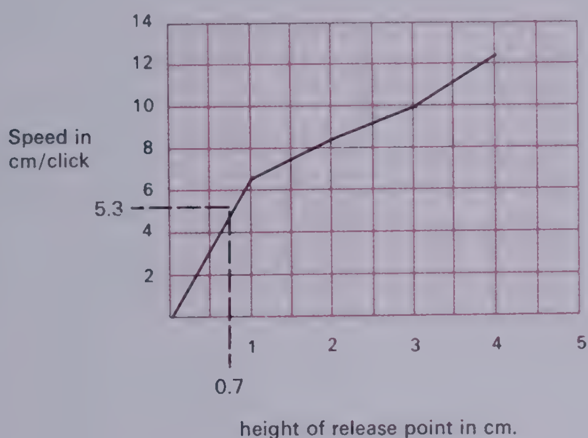


Figure T-9 • 3. Acceptable student graph in response to Interpretation 12*c* based on data from 12*a*.

PROCEDURES

L. Following the sample data, the student should place the steel ball on the inclined track at a height of 0.7 cm above the top of the level track. The time needed for the ball to travel the length of the level track should be about 9½ clicks. If the observed time is different from the time calculated in Interpretation 12*b*, the height of release should be adjusted until the two time values coincide.

INTERPRETATIONS

13. Some students may feel that since the momentum of the marble equals the momentum of the steel ball, the two will behave the same way in a collision. Other students may feel that since the ball and the marble are released from different heights, they will have different energies and behave differently in a collision.

PROCEDURES

M. The steel ball will lose considerable speed, but both balls should roll in the same direction.

N. The marble will bounce back up the incline a little way and will then roll back down. After the collision the speed of the steel ball placed on the level track will be different from the speed of the same ball in Procedure M.

INTERPRETATIONS

14. Two objects with different masses and the same momentum have different amounts of energy.

ON YOUR OWN: Is Seeing Believing?

In Section Two, you were asked to comment on the statement, "Seeing is believing." This activity should help you appreciate the problem of believing what is seen. It should also emphasize that scientific investigations often produce more questions than answers.

You will need a piece of thread and a small lead sinker. Tie one end of the thread to the sinker. Sit in a comfortable position with your elbow resting on the desk or table. Hold the free end of the string so the sinker is about 1 inch above the desk top.

Hold your hand steady and focus your attention *only* on the lead sinker. It usually helps to partially close your eyes while looking at the sinker.

Silently "command" the weight to move back and forth in a straight line. Keep "telling" it over and over again to "move, move, move," and so forth. After a while, change your silent command to "move in a circle to the right, circle to the right, circle to the right," and so forth.

Did the pendulum "obey" your commands?

Determine how many students in your class found that their pendulums moved as commanded and how many found that they did not. If your sinker seemed to move as you commanded, was the movement imaginary or did it *actually* move? How could you answer this question?

Figure 9 • 9.

Energy Conversion

It takes energy to lift a ball to the top of an inclined plane. The higher the ball is lifted, the greater the amount of energy required. In Investigation 8.7, you found that the *force* required to lift a ball is the same no matter how high it is lifted. Energy depends upon two factors: (1) *force*, and (2) *the distance through which that force is exerted.*

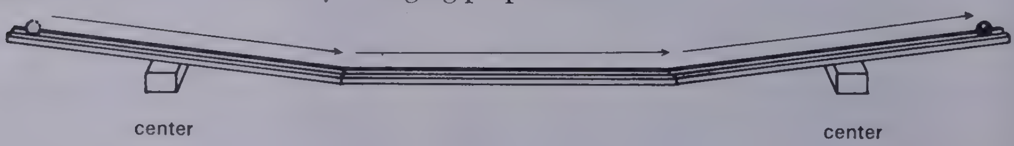
After a ball is lifted to the top of a track, it possesses energy of position, which can be converted into other kinds of energy. The energy possessed by a motionless ball at the top of the track is called *potential energy*, which (in this case) is the result of the force of gravity. Gravitational force causes the ball to accelerate as it rolls to a lower level. A rolling ball possesses energy because it is in motion. The potential energy is gradually changed to energy of motion as the ball moves downhill.

Suppose you add a second inclined plane at the other end of the level track (Figure 9 • 10). When the ball begins rolling uphill, its energy of motion will again be converted to potential energy, and it will slow down. If we ignore friction, we might expect the ball to roll up the second inclined plane until it reaches a height equal to that of its starting point.

Working with a pendulum, we can see a similar example of the change from potential energy to energy of motion and back to potential energy. When a pendulum completes a swing, it comes to a brief but complete stop. At that moment, it has no energy of motion—only potential energy. At the center of its swing, on the other hand, it has no available potential energy—only energy of motion (Figure 9 • 11).

Energy of motion carries the swinging pendulum to its highest point at the end of the swing. Except at the highest and lowest points, both potential energy and energy of motion are present in constantly changing proportions.

Figure 9 • 10.



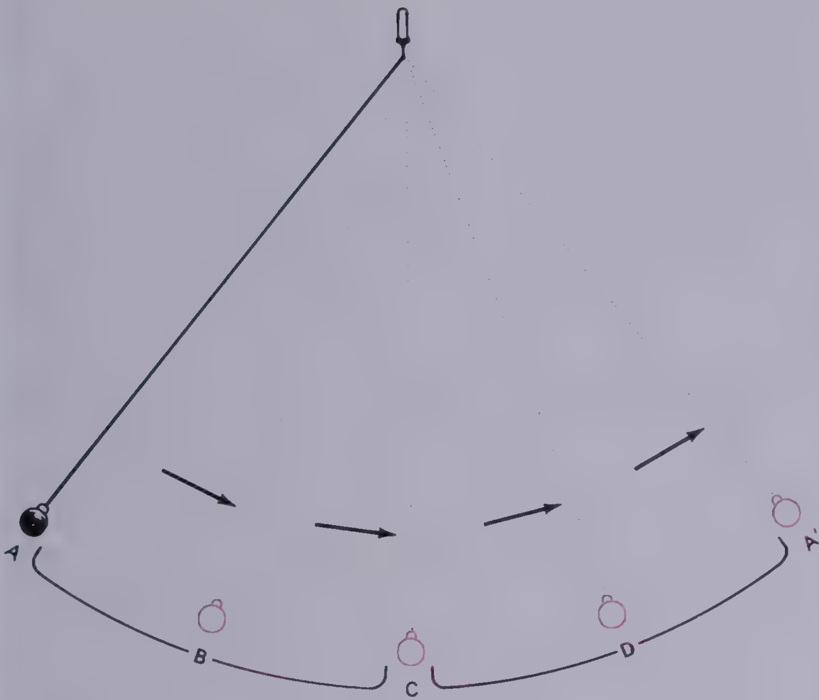


Figure 9 • 11.
The positions of highest potential energy and no energy of motion are *A* and *A′*. *C* is the position of lowest potential energy and highest energy of motion. If the pendulum swings from *A* to *A′*, *B* represents the range of *decreasing* potential energy and *increasing* energy of motion. *D* represents the range of *increasing* potential energy and *decreasing* energy of motion.

INVESTIGATION 9.3: A Study of the Pendulum

The pendulum was one of the first devices used to study time, the force of gravity, and other aspects of physical science. A pendulum is a relatively easy piece of equipment to build, but its behavior is not always easy to explain.

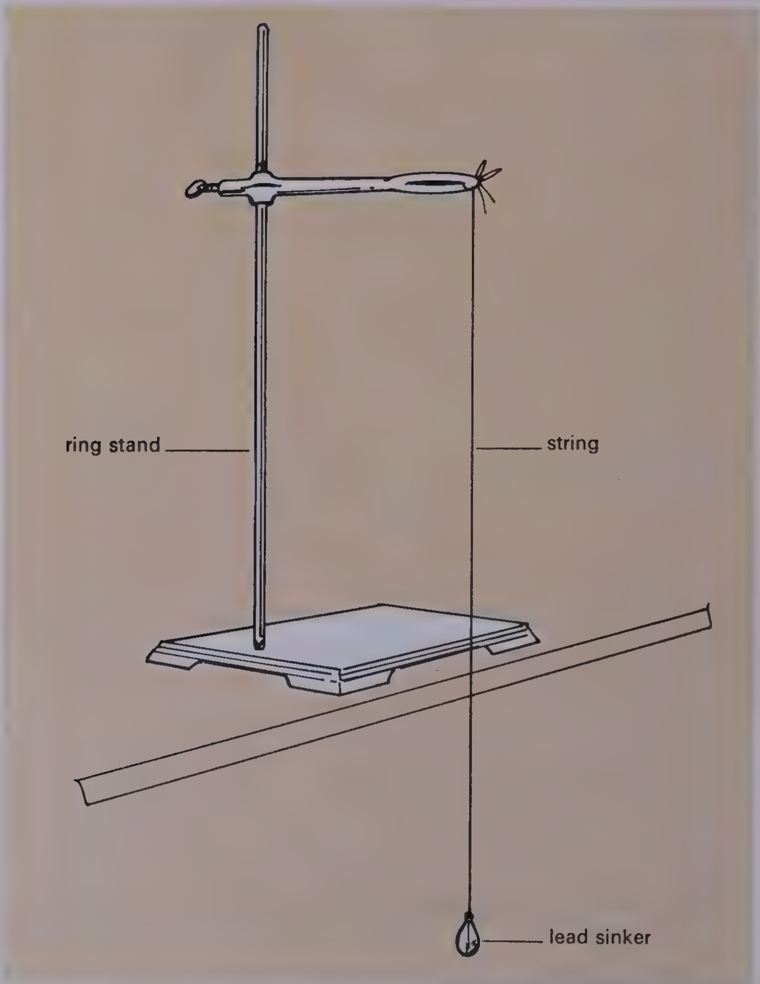
MATERIALS (per team)

- 2 lead sinkers of different weights
- White thread and marking pen
- Screw fastener or other means of attaching the pendulum
- Watch with sweep-second hand
- Meterstick
- Paper clip

PROCEDURES

A. Attach one end of the thread to a fixed support. Tie a paper clip to the other end and hook the heaviest sinker through it (Figure 9 • 12). Pull the pendulum weight about 20 cm from its rest position. Release and determine how much time is required for the pendulum to make twenty complete swings (round trips). Repeat, starting at three or four other distances —such as 15 cm, 10 cm, 5 cm, and so forth—from rest position. For each distance, determine the time for the pendulum to

Figure 9 • 12. Setup for Procedures A–C.



make twenty swings. Record your data on a table similar to Figure 9 • 13 (The time required for one complete round trip is called the *period* of the pendulum.)

Trial	*Distance from Rest Position*	*Time to Complete Twenty Swings*	*Period (Seconds per Swing)*
1	20 cm		
2			
3			
4			

Figure 9 • 13.

INTERPRETATIONS

1. According to your data, what is the period of your pendulum?
2. What seems to be the relationship between the distance a pendulum swings and its period?
3. What would be the period of your pendulum if you released it at a distance of 50 cm from its rest position?

PROCEDURES

B. Repeat Procedure A, but use a lighter sinker. Be sure that the length of the thread is the same as in Procedure A. Before beginning, predict what effect a lighter weight will have on the number of swings per minute. Record your data on a chart like the one used in Procedure A.

INTERPRETATIONS

4. Was your prediction correct?
5. What do you think is the relationship between a pendulum's weight and its period?

PROCEDURES

C. Using the heaviest sinker again and using the same length of thread, cause the pendulum to swing in a circle instead of a straight path. First predict and then determine the time for the weight to go around a circular path one time. Try other varia-

tions of this experiment. Use sinkers of different weights. Make a sinker go in an oval path instead of a circular one.

INTERPRETATIONS

6. What is the relationship of the path of a pendulum to its period?
7. How do the weight, distance, and path of a pendulum affect its period?
8. In your use of a pendulum so far, the weight, distance traveled, and path of swing have varied. The length of the thread remained constant (fixed). Will the pendulum's period be affected if you keep the weight and distance constant but vary the length of the thread? Write a prediction in your notebook.

PROCEDURES

D. Obtain a thread about 2.5 meters long and attach it to the heavy sinker. Lay the thread and weight along a meterstick. Stretch the thread and mark it at the following distances from the center of the weight: 25, 50, 75, 100, 150, and 200 cm.

E. Choose a distance to swing the pendulum (from 5 to 10 cm). Mark this distance in some way so that the pendulum will start at the same release point in all of your trials. You might mark the distance by standing a book or a ring stand at the desired distance from the rest position of the pendulum.

F. Copy Figure 9 • 14. Determine the period of the pendulum for each of the six thread lengths. Record your data.

Figure 9 • 14.

Length	*Distance from Rest Position*	*Time to Complete Twenty Swings*	*Period*
200 cm			
150 cm			
100 cm			
75 cm			
50 cm			
25 cm			

INTERPRETATIONS

9. How did changing the length of the pendulum affect the period?
10. Make a graph of your data. From your graph, find the period for each of the following lengths:

Length in cm	20	30	40	50	60	80	100	160	200
Period in Seconds									

Figure 9 • 15.

11. One useful way to analyze data is to compare ratios. Predict how doubling the length of the pendulum would affect its period. For each ratio shown below, substitute the values obtained in Interpretation 10 and divide the denominator into the numerator. Compare the values obtained.

$$\frac{\text{Period for 40 cm}}{\text{Period for 20 cm}} =$$

$$\frac{\text{Period for 60 cm}}{\text{Period for 30 cm}} =$$

$$\frac{\text{Period for 80 cm}}{\text{Period for 40 cm}} =$$

$$\frac{\text{Period for 100 cm}}{\text{Period for 50 cm}} =$$

$$\frac{\text{Period for 120 cm}}{\text{Period for 60 cm}} =$$

$$\frac{\text{Period for 160 cm}}{\text{Period for 80 cm}} =$$

$$\frac{\text{Period for 200 cm}}{\text{Period for 100 cm}} =$$

12. What determines the period of a pendulum?
13. As an additional activity at home, you might construct a much longer pendulum and test Interpretations 10 and 11.

ON YOUR OWN: Is Seeing Believing?

(page 229)

This investigation should prove interesting to the majority of students. Considerable class discussion may result from students' questions.

A complete explanation cannot be given. Apparently if one concentrates on commanding the pendulum to move, the hand may move slightly in response, thus causing the pendulum to swing. The more one "concentrates" on the pendulum, the greater the chances it will swing. If students repeat the investigation with the pendulum tied to a fixed support, it will not "obey" their commands.

This investigation should illustrate how easily the observer can influence the data. Students *should not* gain the impression that scientists have answers to all problems. The movement of a pendulum you "command" cannot be explained in the usual sense. Yet observations indicate that the pendulum *does* move. Point out that a full explanation of this event is still for the future, when investigators may know more about the relationship between the human nervous system and human behavior.

INVESTIGATION 9.3: A Study of the Pendulum

(pages 231–235)

This investigation is organized to help students isolate variables, collect and graph data, interpolate graphical data, and search for regularities. If your students would profit from a less structured experience, have them design their own investigation in place of this one.

MATERIALS

Plan some means of suspending the long pendulum used in Procedures D, E, and F. A 200-cm pendulum will require a support a little more than 6½ feet above the floor. A suction cup attached to the ceiling will work, but it may leave a mark when removed. A stepladder or a chair placed on top of a table will support the pendulum.

If it is not practical to provide each team with a long pendulum, you might set up one for the class and let teams take turns working with it. The same method might be used for the 150-cm length. Each team should have its own 100-cm and smaller pendulums.

PROCEDURES

A. For the best results the pendulum string should be as long as possible. A length of about 1 meter is good. The length of the string must remain unchanged for Procedures A through C.

INTERPRETATIONS

1. Answers will vary, depending on the setups. Students should observe that the period is approximately the same for each trial.
2. The period of a pendulum does not appear to depend on the distance of swing.
3. The period should be the same as it was in Procedure A if the displacement is 50 cm.

PROCEDURES

B. Many students will predict that the period will change when the weight is changed. Caution the class to be sure the length of the pendulum does not change when the weights are changed.

INTERPRETATIONS

4. The answer depends on the student's prediction.
5. The period of a pendulum does not appear to depend on the pendulum's weight.

PROCEDURES

C. This is a variation of Procedure A. The weight will not maintain perfectly circular or oval paths after it is set in motion, but the period will be constant.

INTERPRETATIONS

6. The period of a pendulum does not appear to depend on its path.
7. Students should be able to generalize about the behavior of a pendulum under the conditions of the investigation. Data indicate that the period of the pendulum does not depend on the pendulum's weight, the distance it swings, or the shape of its path.

   Ask whether there are any similarities between the behavior of a pendulum weight and a ball on an inclined plane.
8. The students may guess that nothing can affect the period of a pendulum, or they may guess that this factor will change it.

PROCEDURES

D. Be sure to caution the students to measure the length of the pendulum from the point of support to the *center* of the weight. The string can be marked before the weight is attached, but the length

should be checked again when the pendulum is suspended. One of the purposes of this investigation is to have students make use of a graph in analyzing data. The 200-cm length is needed for precision in this experiment. Measurement on a pendulum shorter than about 20 cm can introduce a large percentage of error.

E. The student should have discovered previously that the distance through which a pendulum swings is not a factor in determining the period of a pendulum. The purpose of asking them to control the swing in this investigation is to emphasize the idea that all variables but one should be held constant in an investigation.

F. The distances were chosen so that only three of them coincide with the data to be analyzed in Interpretation 11. This will illustrate the usefulness of a graph.

INTERPRETATIONS

9. Decreasing the length of the pendulum decreases the period; increasing the length increases the period.
10. Typical data:

Figure T-9 • 4.

Length in cm	20	30	40	50	60	80	100	120	160	200
Period in Seconds	0.89	1.14	1.25	1.43	1.58	1.75	2.00	2.18	2.61	2.85

These values were obtained from a graph of experimental data.

11. The ratios of the experimental data are as follows:

$$\frac{\text{Period for 40 cm}}{\text{Period for 20 cm}} = \frac{1.25}{0.89} = 1.40$$

$$\frac{\text{Period for 80 cm}}{\text{Period for 40 cm}} = \frac{1.75}{1.25} = 1.40$$

$$\frac{\text{Period for 120 cm}}{\text{Period for 60 cm}} = \frac{2.18}{1.58} = 1.38$$

$$\frac{\text{Period for 200 cm}}{\text{Period for 100 cm}} = \frac{2.85}{2.00} = 1.42$$

$$\frac{\text{Period for 60 cm}}{\text{Period for 30 cm}} = \frac{1.58}{1.14} = 1.38$$

$$\frac{\text{Period for 100 cm}}{\text{Period for 50 cm}} = \frac{2.00}{1.43} = 1.40$$

$$\frac{\text{Period for 160 cm}}{\text{Period for 80 cm}} = \frac{2.61}{1.75} = 1.49$$

Doubling the length of the pendulum seems to increase the period of the pendulum by a factor of about 1.4.

An alert student may notice that increasing the length of a pendulum by a factor of 2 increases the period by the square root of 2. If he wishes to analyze the data further, he should find that the change in the period depends upon the square root of the factor by which the length is changed.

12. The factor for which the students have the most information is pendulum length. There are other factors, the most significant of which is the force of gravity.

    A pendulum can be used to measure the acceleration of gravity. If students would like to do this, they can apply the data already obtained to the formula below:

$$g = 4\pi^2 \frac{L}{T^2} \text{ or, more simply, } g = 39.48 \frac{L}{T^2}$$

where g = acceleration of gravity
π = 3.1416 (approximately)
L = length of the pendulum
T = period of the pendulum

The acceleration of gravity measured in the metric system is 980 cm/sec/sec, and in the English system 32 ft/sec/sec.

The derivation of this formula is much too difficult for most students at this level. Using the formula should be an optional exercise for your more interested and capable students.

Momentum and Energy

Figure 9 • 16. Examine the photos and answer the related questions. Give reasons for your answers.

Does the skier have momentum? Does he have energy of motion? How does his speed change?

Assume that Player number 70 collides with Player number 25. Which player has the greater momentum? What are the likely results of a collision? How could either player increase his momentum?

Describe the scene *at left* in terms of momentum, energy of motion, and potential energy. Assuming a hit, describe the transfer of energy after contact of bat and ball in the same terms.

What is the source of the energy of the bowling ball? How is the energy being used? Account for the energy after the ball meets the pins and stops.

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Figure 9 • 16. Momentum and Energy

(pages 236–237)

The skier has both momentum and energy of motion, since he has both mass and speed. His speed, in midair, will be affected by the force of gravity.

Football player number 70 appears to be larger and is certainly moving faster than the player with the ball, number 25. Number 70 therefore appears to have more momentum. It appears likely that number 25 will be tackled or knocked to the ground by the collision. Either player could increase his momentum by increasing his speed. In the longer run, both players might gain weight to increase their potential momentum; however, since a weight gain might result in a loss of speed, a net increase in momentum might be negligible.

The baseball has both momentum and energy of motion; the bat has potential energy. A hit will transfer energy of motion from the swinging bat to the ball, resulting in a change of direction for the ball, since it has less momentum, generally, at the time of contact.

The energy of the bowling ball would come from two sources: the bowler's muscle energy and the force of gravity on the ball. Some energy is used in rolling down the alley and some is transferred to the falling pins. A large part of the energy of the rolling ball is expended at the back of the alley as it drops into a trough or strikes the back wall.

SUPPLEMENTARY MATERIALS

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SUGGESTED ACTIVITIES FOR TESTING LABORATORY SKILLS AND TECHNIQUES

INVESTIGATION 9.2

Adjust an inclined track to a specified slope.
Measure the slope of an inclined track.

INVESTIGATION 9.3

Time an event, using a sweep-second hand.
Measure the length of a pendulum.
Release a pendulum at a specified distance from the rest position.

SECTION TEN

Phases of Matter

SECTION TEN

Phases of Matter

(pages 239–255)

Preview

Most people are vaguely aware that matter exists in three phases: solids, liquids, and gases. But how many really understand how the three phases of matter interact with each other and under what conditions matter will exist in a particular phase?

During the first investigation of Section Ten, students are given a blank (uncalibrated) alcohol thermometer and are asked to calibrate it in degrees Celsius using the boiling and freezing points of water to establish a range of 0°C to 100°C. Students are then asked to interpolate degrees Celsius between these two points and to extrapolate degrees Celsius below the freezing point of water. They will have an opportunity to record temperatures as low as −75°C if they perform the optional Investigation 10.4.

The student-calibrated thermometers are used in a number of investigations involving the relationship between water and ice; the effect upon the freezing point of water when salt, sugar, and alcohol are added; and the behavior of matter subjected to very low temperatures. An "On Your Own" investigation permits students to take their calibrated thermometers home to determine various temperatures, both indoors and outdoors.

There is a reading selection, together with diagrams, on the modern model for the structure of water molecules, and their tendency to be polarized.

An Inquiry Demonstration to be performed *only* by the teacher allows students to observe what happens to matter when it is immersed in a solution of acetone and dry ice. The results are rather spectacular, and students should gain still more information about their model for the structure of matter. The opening photograph of this section shows a beaker of acetone and dry ice with a heavy coating of frost. The photo was taken 25 minutes after the opening photograph

of Section Five, which shows the more violent initial reaction of dry ice and acetone.

As in all sections, activities for testing student performance in laboratory skills and techniques are included.

PLANNING AHEAD

Please read through the section to make sure you have the materials on hand for each investigation.

LEARNING OBJECTIVES

Given the opportunity to inquire, to investigate, to interpret data, and to offer hypotheses about the activities in this section, most students should be able to—

- Calibrate a simple measurement device;
- Interpolate or extrapolate from known data;
- Develop a model for the behavior of matter at low temperatures;
- Relate the apparent calorie loss when water freezes to the nature of bonding in crystals or solids;
- Explain the assumptions which underlie the construction of the liquid-in-glass type thermometer;
- Compare the accuracy of their own calibrations with those on commercially manufactured thermometers (room thermostats, laboratory thermometers, medical thermometers);
- Explain the behavior of water in terms of polar molecules;
- Offer models about the depression of the freezing point caused by the addition of various chemicals to water;
- Relate the energy associated with phases and changes of matter to actual situations (ice melting in a drink, salt on an icy road, role of antifreeze, etc.);
- Offer models to explain change in the states of matter as a function of energy;
- Recognize a relationship between molecular movement and heat energy and begin to refine their model for matter to include energy of molecular motion.

Science textbooks classify matter into three forms, or phases: solids, liquids, and gases. But why is a solid *solid*, a liquid *liquid*, and a gas *gas*? Are each of these phases the result of chemical interactions or of a combination of both chemical and physical interactions? Are there really only three phases of matter? The next series of investigations should help you to resolve some of these questions.

INVESTIGATION 10.1: Calibrating a Thermometer

A thermometer measures changes in temperature. Thermometers can also reveal information about relationships between matter and energy. Like most scientific instruments, thermometers vary in cost from a few pennies to hundreds of dollars. Selection of a thermometer depends upon the purpose for which it is to be used. Because you will not need to make exact measurements of variations in temperature, an inexpensive thermometer will be used in this investigation.

There are many kinds of thermometers. The thermometers doctors use to measure body heat contain mercury. You will use an alcohol thermometer. When the temperature of liquids such as alcohol or mercury is increased, their volumes increase. When a given amount of such a liquid is confined within a tube, an increase in volume results in a longer column of liquid. Therefore, the longer a column of alcohol or mercury, the higher the temperature. Lower temperatures are indicated by a decrease in the length of the liquid column.

The first task will be to calibrate (mark) temperature on an alcohol thermometer. You will then use this thermometer to investigate certain properties of matter that involve both chemical and physical interactions.

MATERIALS (per student)

Uncalibrated alcohol thermometer
Flat stick, 15 cm long
Plastic millimeter rule

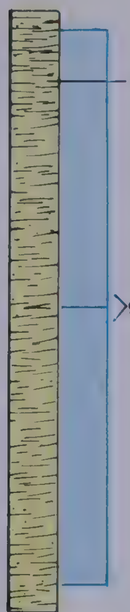


Figure 10 • 1. Setup for Procedure A.

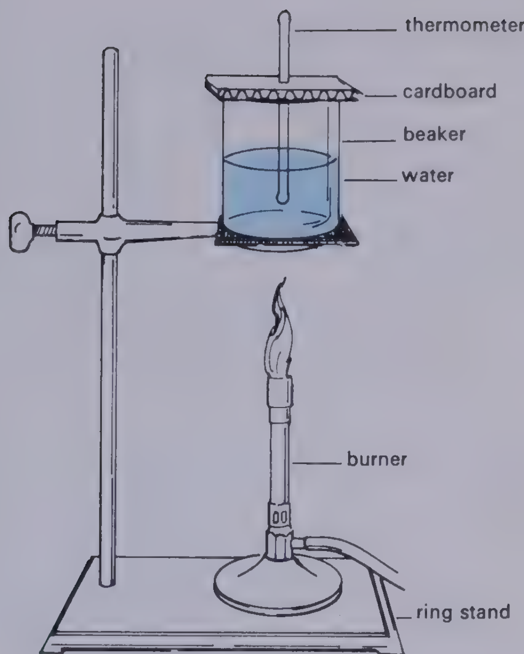


Figure 10 • 2. Setup for Procedure B.

MATERIALS (per team)

- Roll of freezer tape
- Water bath
- Beaker of crushed ice
- Piece of cardboard to cover beaker
- Scissors

PROCEDURES

At sea level, water boils at 100°C (212°F) and freezes at 0°C (32°F). The boiling point decreases about 1°C for each 1000-foot increase in elevation. We can use the boiling and freezing points of water to locate temperature values on our thermometer.

A. Cut a piece of freezer tape about 6 mm wide and equal to the length of your thermometer (with the bulb exposed). Place this tape on the flat stick as illustrated in Figure 10 • 1.

B. Prepare a water bath as shown in Figure 10 • 2. Place the thermometer in the beaker of water. The level of alcohol will con-

tinue to rise until the water boils. When the water boils, the alcohol should stop rising and remain at a fixed level. Measure the distance (in mm) from the *top* of the thermometer to the top of the alcohol. Record this measurement in your notebook.

C. Allow the thermometer to cool. Then immerse it for several minutes in a beaker or jar half-filled with crushed ice (see Figure 10 • 3). When the length of the alcohol column no longer changes, measure the distance from the top of the thermometer to the top of the alcohol. Record this measurement in your notebook.

Figure 10 • 3. Setup for Procedure C.

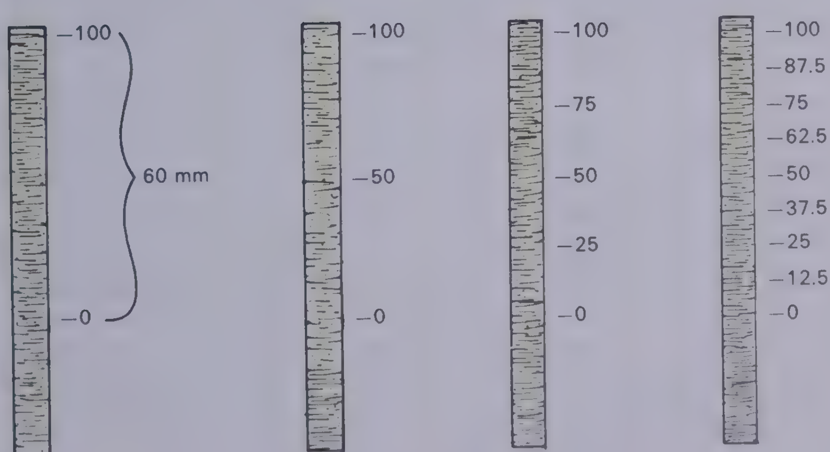
D. Use an atlas to find the elevation (height above sea level) in your area. Assuming that the boiling point decreases 1°C per 1000 feet above sea level, calculate the boiling point of water in your area.

E. Measuring from the top of the tape, mark off a distance equal to the distance you recorded when the thermometer was in

boiling water. Label this point *100°C* or whatever the boiling point of water is in your area (see Procedure D). Again measuring from the top of the tape, mark off a distance equal to the distance you recorded when the thermometer was immersed in the beaker of ice. Make another mark on the tape at this point and label it *0°C*.

F. Place your ruler alongside the tape so that 0 mm is aligned with 0°C. Calculate the number of mm to the point midway between 0°C and the boiling point. Mark this point and label it *50°C* (or less, if you live in an area that is 1000 feet or more above sea level). For example, suppose the distance from 0° to 100° on your tape is 60 mm. Half of 60 is 30, so you would place a mark at 30 mm. If the elevation of your area is only a little above sea level, you would label the midpoint *50°C*. But if you found that your area is about 5000 feet above sea level, the boiling point of water would be approximately 95°C. Therefore the mark halfway between 95° and 0° would be 47.5°C. Mark off and label as many intermediate units as possible on your tape (see Figure 10 • 4).

Figure 10 • 4. Calibrating tape for a thermometer.



You might calibrate your thermometer by determining degrees per millimeter. If 100°C is equivalent to 60 mm, then 10°C is equivalent to 6 mm. You could then mark your tape at 6-mm intervals to indicate each 10-degree difference in temperature.

G. In your notebook, make an exact copy, *to scale*, of the marks on your tape. Carefully remove the tape from the flat stick. Fasten it to the thermometer so that the top end of the tape is exactly even with the top end of the thermometer. The tape should not hide the alcohol in the tube. The bulb at the bottom *must not* be covered with tape.

H. Test your thermometer. Determine room temperature, your own body temperature, and the temperature of tap water.

CAUTION: *Do not place an unsterilized thermometer in your mouth. To measure body temperature, place the thermometer under your arm or hold it in the palm of your hand.*

I. If possible, compare your results with results obtained with mercury thermometers. How does the accuracy of your thermometer compare with those used for professional purposes?

J. Place the thermometer in a safe place until needed.

FOR CLASS DISCUSSION

1. In a thermometer, a change in the height of a column of liquid indicates a change in temperature. Using your understanding of the nature of matter, explain why the height of the column of liquid in a thermometer increases with the temperature.
2. The most accurate thermometers are not of the liquid-glass type. From your experience in calibrating a thermometer and from a comparison of your thermometer with those of other students in your class, suggest possible reasons for this.

INVESTIGATION 10.1: Calibrating a Thermometer

(pages 240–244)

From this investigation students should learn how to calibrate a thermometer and how to measure temperatures.

MATERIALS

The success of this investigation and the later usefulness of the thermometers will depend upon the care exercised by students in measuring and marking during the procedures.

Tongue depressors or ice-cream sticks can be used for calibration. Mount the thermometer on a tongue depressor and fasten the top and bottom (just above the bulb) with freezer tape. Then calibrate the thermometer as described.

PROCEDURES

A.–E. No comment.

F. Errors students make when calibrating the thermometers probably will be large compared with errors arising if the boiling point of water was taken to be 100°C at elevations lower than 2000 feet. Since the boiling point decreases about 1°C for each 1000 feet increase in elevation, corrections should be made for any elevation above 2000 feet. Correction for the boiling point is easy, but more calculation is required in determining points *between* freezing and boiling. Students may prefer to determine intermediate points by means of the degrees-per-mm method.

G. Tape adheres better when it is applied to a dry thermometer.

H. No comment.

I. If several mercury thermometers are available, you may find that they differ from each other and from the alcohol thermometers by as much as 1 degree. If the mercury thermometers are calibrated from 0° to 100°C, have students check their accuracy at the freezing and boiling points.

J. No comment.

FOR CLASS DISCUSSION

1. Matter is composed of atoms and molecules. As temperature increases, particles in liquid require more space. Some students may explain this by suggesting that as matter becomes hotter, particles become larger. Others may suggest that particles move more violently as temperature increases—therefore, they require more space.

2. The tube diameter may not be uniform in a glass thermometer. This would mean that a 1-millimeter change in the height of the liquid at one point in the tube would not be equivalent to a 1-millimeter change at another point. The calibrations on most laboratory thermometers are stamped on by machine. Because of this, any variation in the tube's size or in the bulb's volume will lead to an error larger than the error that would result if the thermometers were calibrated by hand.

Structure of Water Molecules

All life on earth depends upon water in one way or another. Until recent years, when people talked about natural resources, they mentioned oil, iron ore, forests, and so forth, but seldom included water. Yet water may be our most important natural resource.

Early alchemists searched for a universal solvent, a liquid in which anything would dissolve. Such a solvent has never been discovered and probably does not exist. Water comes closest to this ideal; more kinds of substances will dissolve in water than in any other known liquid. Much of our knowledge of chemistry is based on the relationship between molecules of water and molecules of other substances.

So far we have used the formula H_2O to indicate water. This formula tells us that there are two hydrogen atoms and one oxygen atom in a water molecule, but it does not tell us how the atoms are arranged in the molecule. Chemists use a different kind of formula to show the arrangement of atoms in a molecule. Remember that formulas represent models and not pictures of atoms.

For convenience we may wish to represent a water molecule in this way:

$$\text{H-O-H}$$

Then we could write the equation for a reaction between sodium (Na) and water thus:

$$2\,\text{Na} + 2\text{H-O-H} \longrightarrow 2\text{Na-O-H} + \text{H-H}$$

The dashes represent *electron bonds* that hold the atoms together. Many reactions are written this way, because it is a convenient method of conveying information, as we will see later.

Recall that angles are measured in degrees. A circle has 360 degrees; half a circle, 180 degrees; a quarter of a circle (a right angle), 90 degrees; and so forth. This same system is used to measure the angles formed by chemical bonds. Chemists' experiments indicate that this kind of model of a water molecule should

be written H⌒O⌒H instead of H-O-H, because the three atoms apparently are not arranged in a straight line. Experiments also indicate that the angle formed by bonds between the three atoms is about 105° (Figure 10 • 5).

The angle between the bonds in a molecule is important because it is related to the concept of *polarity*. A molecule is said to be polar when one side of it is more negatively charged than another. Recall that electrons carry a negative charge. In a polar molecule, electrons tend to move toward one side, giving the molecule positive and negative regions.

With sensitive apparatus, the polarity of water molecules can be demonstrated by placing a container of water between two electrically charged plates. Many of the water molecules line up so that the positive poles of the molecules face the negative plate and the negative poles of the molecules face the positive plate (see Figure 10 • 6).

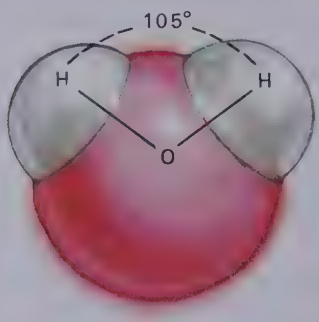


Figure 10 • 5. Structural model of a water molecule, with an angle of about 105° between the bonds.

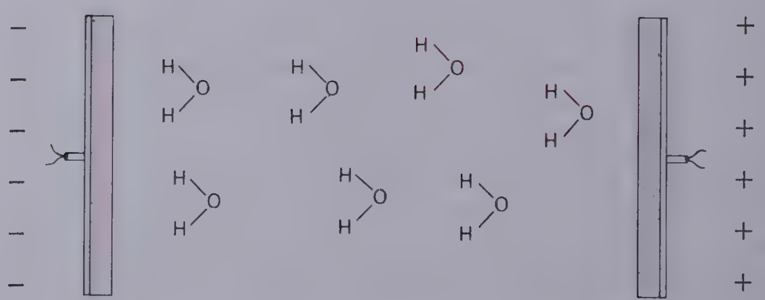


Figure 10 • 6. Diagram showing orientation of water molecules in an electric field.

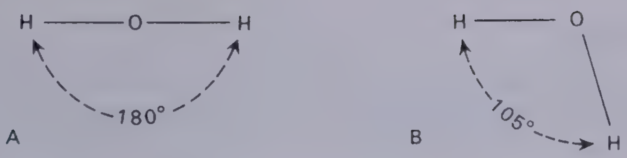


Figure 10 • 7. Diagram showing two possible arrangements of atoms in a water molecule. The arrangement in *A* would cause zero polarity. Only the arrangement in *B* agrees with the actual data.

The polarity of a molecule is determined by two factors: (1) the kinds of atoms that make up the molecule, and (2) the angles formed by the bonds. In a water molecule, the hydrogen atoms attract electrons less strongly than the oxygen atom does. This causes the hydrogen atoms to have a positive charge and the oxygen atom to have a negative charge.

If the three atoms in a water molecule were arranged in a straight line (Figure 10 • 7*A*), each end would be positive, and the center would be negative. Such a molecule would not be polar because it would not have a negative end.

However, the actual bond angle of water molecules has been established as about 105° (Figure 10 • 7*B*). The oxygen atom, which has a negative charge, lies to one side rather than just between the two hydrogen atoms, which have positive charges. Therefore, the water molecule is polar.

The carbon dioxide (CO_2) molecule does not appear to be polar; it is thought to have a structure like that in Figure 10 • 8.

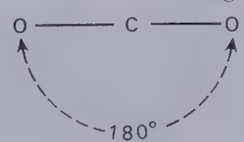


Figure 10 • 8. Diagram of a carbon dioxide molecule with zero polarity.

The angles formed by bonds are not the only factors that determine polarity. The atoms of some elements attract electrons better than others. A hydrogen chloride (HCl) molecule is electrically neutral, yet it is polar because Cl attracts electrons more strongly than H. Thus H-Cl molecules would line up in an electrical field with their hydrogen (positive) ends toward the negative plate and their chloride (negative) ends toward the positive plate. A hydrogen molecule (H-H) is nonpolar, since the attraction of electrons is no stronger in one atom than in the other.

Understanding the behavior of polar and nonpolar molecules is important, because it will help you interpret the results of many investigations to follow.

PROBLEMS

1. Atoms that tend to gain electrons form negative ions. Atoms that tend to lose electrons form positive ions. Which family on your modified periodic chart (page 100) has atoms that are most likely to form the negative part of a polar molecule? Which family has atoms that are most likely to form the positive part of a polar molecule?
2. If the angle between the bonds of a water molecule were 90°, would you expect the polarity of this molecule to be greater or less than that of a normal water molecule? Explain.
3. Name several problems of critical importance that man faces in his attempt to conserve both the quantity and quality of water.
4. Name several ways living things depend upon water.

INVESTIGATION 10.2: Water and Ice

Like many liquids, water contracts as it cools—its volume decreases. When the temperature reaches about 4°C, however, water starts to behave in a different way. In this investigation, you will observe the volume of water in two phases, solid and liquid.

MATERIALS (per team)

Test tube containing ice
Metric ruler

PROCEDURES

A. Measure and record the depth of the ice in the tube.
B. Melt the ice by holding the test tube in your hand.
C. Measure and record the depth of water in the tube.

INTERPRETATIONS

1. Suggest a model that might explain the change in volume as ice melts to form water. Your model should take into account

the shape and polarity of water molecules, and the difference between particles in a liquid and in a solid.

2. According to your model, which should have a greater density —ice or water?
3. Check Figure 10 • 9. Does this change the model you suggested in Interpretations 1 and 2?

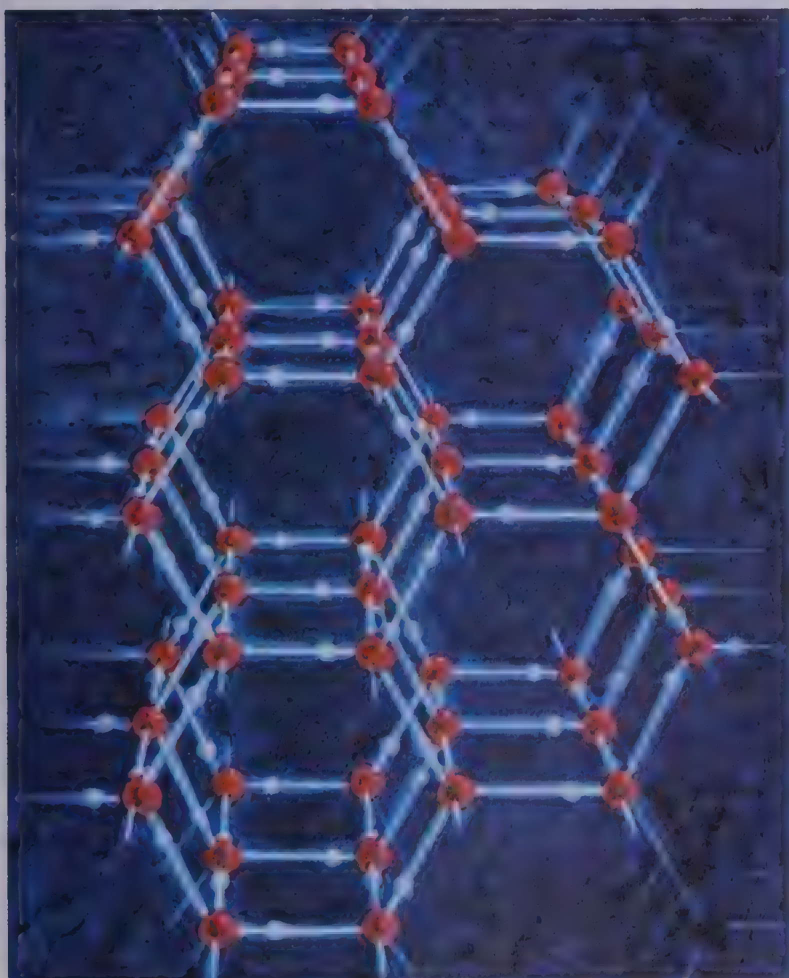


Figure 10 • 9. Structural model of ice molecules. The large red spheres represent oxygen atoms. They are bonded together by hydrogen atoms, represented by the small white spheres.

Structure of Water Molecules

(pages 245–248)

It is easy to demonstrate that water molecules are attracted to positive or negative charges. Rub a plastic ruler with wool or plastic wrap and hold it near a thin stream of running water. The stream will be deflected toward the ruler. The general rule for solubility is: Molecules of polar substances will dissolve in a polar liquid, and molecules of nonpolar substances will dissolve in a nonpolar liquid. If water molecules were nonpolar, life as we know it could not exist. For example, minerals necessary for the growth of plants must be soluble in water to be absorbed by roots. Many biochemical processes occurring within living systems depend upon the polarity of water molecules.

PROBLEMS

1. Atoms in the fluorine family are most likely to form the negative part of a polar molecule. Hydrogen atoms and atoms in the lithium family are most likely to form the positive part of a polar molecule.
2. If the angle between the bonds of a water molecule is less than 105°, the polarity of the molecule would be greater than that of a normal water molecule. If the angle is close to 0°, the positive charges of both hydrogen atoms will exert their forces in almost the same direction.
3. There are many possible answers that students suggest. Industry could not survive without water. Without water for irrigation many farms could not operate, and there would be a serious food shortage. Much of our electrical power is generated by water. Water is needed to cool nuclear-powered generators. Encourage students to think of these and other ways water is important.
4. Human life depends upon water as do all forms of life. Forms that live part or all of their lives in water could not survive.

   This question is not difficult and is designed for students who have trouble understanding science.

INVESTIGATION 10.2: Water and Ice

(pages 248–249)

Students should be encouraged to interpret the decrease in volume for a given number of water molecules as they change from solid to liquid as further evidence for the bent shape of water molecules.

MATERIALS

It will probably be necessary to put the test tubes of water into the freezer on the day before this investigation is scheduled. The test tubes should be about ¾ full. New test tubes are less likely to break when water freezes. You should freeze more test tubes than the number needed by your class, to allow for possible breakage or student error.

PROCEDURES

A.–B. No comment.

C. The depth of the water should be less than the depth of the ice.

INTERPRETATIONS

1. We hope that students will suggest a model to explain the difference between ice and water based on their knowledge of the polarity and geometry of water molecules.

   In ice, water molecules are arranged in rings. Hydrogen atoms and oxygen atoms occupy adjacent positions in the rings because of the attraction of their opposite charges.

   When heat is added to ice, the vibration of the molecules is increased. At the melting point, this motion is so great that the attraction between molecules can no longer hold them in position. As soon as the molecules are free to move, they occupy some of the space in the center of the rings and are usually closer together.

   It is not likely that students will offer such a detailed answer. They should see that because of the bent shape of the molecules and the attraction between hydrogen and oxygen atoms, it would be difficult to achieve an orderly arrangement which would conserve space.

2. Water molecules in liquid water are not arranged in a pattern. They are moving rapidly and continually bumping into one another. When water freezes, the molecules of water slow down, and crystals form. These crystals are arranged in a pattern. Water molecules in an ice crystal are arranged in a pattern that includes many spaces between the molecules. As ice melts, this arrangement collapses. Therefore, although ice has a greater volume than the water from which it was formed, the spaces between the molecules of water give ice less density than water.

   Refer students to Figure 7 • 14 and ask them to explain the behavior of the iceberg in terms of densities.

3. Figure 10 • 9 is an illustration of an ice crystal. Ice is less dense than liquid water because between each two oxygen atoms there must be a hydrogen atom. As a consequence, there are large, empty spaces in ice.

INVESTIGATION 10.3: Ice, Salt, Sugar, and Alcohol

At sea level, water boils at 100°C and freezes at 0°C. Body temperature, room temperature, and the temperature of tap water all fall somewhere between 0°C and 100°C. In this investigation, you will study temperatures that are below 0°C.

MATERIALS (per student)

Beaker (250 ml) or jar
Alcohol thermometer (used in Investigation 10.1)
Spoon or mixing stick

MATERIALS (per class)

Finely crushed ice
Table salt
Table sugar
Ditto fluid or wood (methyl) alcohol

PROCEDURES

A. Calibrate your alcohol thermometer below the zero mark. Do this by assuming that the liquid in your thermometer will move the same distance per degree below zero as it does per degree above zero. Mark the tape (in degrees centigrade) as accurately as possible.
B. Pour crushed ice into the 250-ml beaker or jar until it is about half full.
C. Insert your thermometer into the crushed ice so that the bulb is well below the surface.
D. When the reading is 0°C, add an amount of table salt equal to about ⅓ the amount of ice. Mix well with a small spoon or stick, while holding the thermometer in position. Carefully observe the thermometer for five minutes. Record the new temperature. Empty and rinse the beaker.
E. Repeat Procedures A, B, and C, but use sugar in place of salt. Record your observations. Repeat again, using alcohol instead of salt or sugar. Record your observations.

INTERPRETATIONS

1. Propose a model that explains how salt caused the change in temperature you observed. In your model, consider the structure of a water molecule and the electrical conductivity of salt in solution.
2. Why is salt sprinkled on roads during the winter in some parts of the country?
3. Explain why salt, sugar, and alcohol each cause a different temperature change when added to crushed ice.

OPTIONAL PROBLEMS

The molecular weights of methyl alcohol, table sugar (sucrose), and common salt (NaCl) are 32, 342, and 58.5, respectively. Each "molecule" of NaCl forms one sodium ion and one chloride ion. These ions behave as free particles in solution. Each molecule of sugar or of alcohol exists as a single particle in solution.

Suppose you prepared the solutions listed in Figure 10 • 10. Then suppose you measured the freezing point of each solution

Grams of table sugar per liter of solution	10	20	40	80
Freezing point	−0.06°C	−0.11°C	−0.22°C	−0.44°C
Grams of methyl alcohol per liter of solution	10	20	40	80
Freezing point	−0.57°C	−1.14°C	−2.30°C	−4.60°C
Grams of sodium chloride per liter of solution	10	20	40	80
Freezing point	−0.60°C	−1.17°C	−2.32°C	−4.63°C

Figure 10 • 10.

with a very accurate thermometer and obtained the data shown in the table. (Recall that the freezing point of pure water is 0°C.)

1. For each solution, calculate the number of moles in 80 grams.
2. For 1 mole of particles, how much would the temperature be lowered?

ON YOUR OWN: Researching Temperatures

If possible, take your calibrated thermometer home and determine the temperature of various areas in and about your home.

You might try to determine the temperatures—

1. of water from your hot water faucet;
2. of the freezing compartment and the regular food storage area of your refrigerator;
3. of the inside and outside of your home and of various rooms within your home.

You might wish to determine the efficiency of your heating (or cooling) system. You probably will think of other uses for the thermometer. If you plan to determine temperatures of liquids other than water, please check with your teacher before proceeding.

INVESTIGATION 10.4: Behavior of Matter at Low Temperature *(Optional)*

Many gases, such as nitrogen, oxygen, and hydrogen, can be liquefied. In a liquid state, these gases are extremely cold. A rubber ball, a piece of celery, a hot dog, or a person's finger, if immersed in these liquids, freezes almost instantly and becomes extremely brittle.

This investigation will deal with the behavior of matter under conditions of extreme cold.

MATERIALS (per student)

- Calibrated alcohol thermometer
- Dry ice
- Sack (heavy cloth or heavy paper)
- Pyrex beaker (250 ml)
- Ice water
- Pyrex test tube
- Ditto fluid

CAUTION: *Dry ice is extremely cold and may cause severe injury if it is allowed to come in contact with your hands. Use tongs, pliers, or asbestos gloves to handle dry ice.*

PROCEDURES

A. Place dry ice in a heavy cloth or paper sack and crush with a hammer until the dry ice has the consistency of coarse sand.

B. Pour crushed dry ice into a 250-ml Pyrex beaker until it is half full.

C. Precool your calibrated alcohol thermometer in ice water. Insert the thermometer into the dry ice and determine the temperature as accurately as possible. Record in your notebook.

D. Half fill a Pyrex test tube with Ditto fluid and mark the level carefully. Then carefully lower the tube into the dry ice. Wait five minutes and then remove the tube. Was there any change in the volume of the Ditto fluid? Try to obtain the same results by leaving a test tube of Ditto fluid in a freezing compartment overnight.

INTERPRETATIONS

1. Compare Ditto fluid with water in terms of—
   a. change in volume from liquid to solid;
   b. freezing point.
2. Why is there such a difference between the temperature of dry ice and that of ordinary ice?
3. What practical applications of mixing different substances with water can you suggest as a result of your having performed this investigation?

INVESTIGATION 10.3: Ice, Salt, Sugar, and Alcohol

(pages 250–252)

This investigation is an introduction to the change in temperature of water when other substances are added to water. The temperature of the mixture can then be compared to that of pure water.

When students modify their model for the behavior of matter to include the effect of attractions between particles on temperature, they should be able to explain their observations in this investigation.

MATERIALS

For best results the ice should be crushed to the consistency of coarse sand.

PROCEDURES

A.–C. No comment.

D. The mixture of salt and ice should produce a temperature of approximately $-20°C$. Results obtained by students will vary slightly depending upon the amount of salt, how well it was mixed with the ice, and how carefully the thermometers were calibrated.

E. The volumes of sugar and alcohol added to crushed ice should be about the same as the volume of salt added in Procedure D. We have found that crushed ice plus approximately ⅓ of the same volume of sugar results in a temperature of approximately $-4°C$. The alcohol and crushed ice mixture yields a temperature of about $-13°C$.

INTERPRETATIONS

1. When sodium ions and chloride ions are interspersed among water molecules, the behavior of the molecules of water is affected. This effect depends upon the concentration of ions from salt. The presence of sodium and chloride ions in water interferes with the ability of water molecules to become properly aligned to form ice crystals.

   The temperature must be lowered before the ions are forced to separate from water molecules so that ice can form. Conversely, ions in salt attract water molecules in ice and can cause ice to melt by absorbing heat from the surroundings.
2. Salt will prevent ice from forming as long as the temperature of the air (or road surface) remains above the freezing point of salt water.
3. At low concentrations of solutes, the effect of dissolved particles on the freezing point is almost directly proportional to the concentra-

tion of solute particles. Since sodium chloride dissociates into sodium and chloride ions, 1 mole of NaCl yields 2 moles of particles (1 mole of sodium ions and 1 mole of chloride ions). Because alcohol and sugar do not break apart to form ions, 1 mole of alcohol or sugar yields but 1 mole of particles in solution. But the formula weights of the three substances are different. Assuming that students added approximately 40 ml of each solute to the ice mixture, the relationships shown in Figure T-10 • 1 result.

Figure T-10 • 1.

Material	*Amount*	*Density g/ml*	*Weight*	*Mole Weight*	*Moles of Particles*
Sugar (sucrose)	40 ml	1.588	64 g	342.0	0.2
Alcohol	40 ml	0.796	32 g	32.0	1.0
Salt	40 ml	2.165	87 g	58.5	3.0*

*Based on two moles of ions per molecular weight.

OPTIONAL PROBLEMS

(pages 251–252)

Students may enjoy calculating the relationships between concentration of solute particles and freezing point depression. This provides additional opportunity for them to work with the mole concept. If your students have been successful in preparing graphs, have them plot grams per liter against freezing point depression, and moles per liter against freezing point depression.

1. Students may obtain the formulas for sugar and methyl alcohol in Figure 5 • 5.
2. Answers appear in Figure T-10 • 3.

Figure T-10 • 2.

Substance	*Formula*	*Molecular Weight*	*Moles in 80 g*
Sugar	$C_{12}H_{22}O_{11}$	C $12 \times 12 = 144$ H $22 \times 1 = 22$ O $11 \times 16 = 176$ 342 g/mole	$\frac{80\ g}{342\ g/mole} = 0.234$
Methyl alcohol	CH_3OH	C $1 \times 12 = 12$ H $3 \times 1 = 3$ O $1 \times 16 = 16$ H $1 \times 1 = 1$ 32 g/mole	$\frac{80\ g}{32\ g/mole} = 2.50$
Sodium chloride	NaCl	Na $1 \times 23.0 = 23.0$ Cl $1 \times 35.5 = 35.5$ 58.5 g/mole	$\frac{80.0\ g}{58.5\ g/mole} = 1.37$

Substance	*Moles of Particles*	*Temperature Change*	*Temperature Change per Mole of Particles*
Sugar	0.234	$-0.44°$	$\frac{-0.44°}{0.234 \text{ mole}} = -1.88°/\text{mole}$
Methyl alcohol	2.50	$-4.60°$	$\frac{-4.60°}{2.50 \text{ moles}} = -1.84°/\text{mole}$
Sodium chloride	1.37 moles of NaCl, but 2.74 moles of particles*	$-4.40°$	$\frac{-4.40°}{2.74 \text{ moles}} = -1.60°/\text{mole}$
		Average	$\frac{-5.32°}{3} = -1.77°/\text{mole}$

Figure T-10 • 3.

*The moles of particles in NaCl are twice the number of moles of NaCl, because each NaCl gives one Na^{+} ion and one Cl^{-} ion. The sodium chloride and methyl alcohol solutions were in excess of 1 molar concentration. At these concentrations, particles may interfere with one another. This would account for deviations from the average. To test the hypotheses, students could repeat the calculations for the other weights given.

FOR ADDITIONAL ACTIVITY

Students may enjoy making "ice cream." Milk and sugar in a test tube can be frozen in a beaker of crushed ice and table salt mixture. The milk and sugar should be stirred with a stick from an ice-cream bar. It should take about fifteen minutes to freeze.

ON YOUR OWN: Researching Temperatures

(page 252)

Students can extend their ability to use their own calibrated thermometers by determining the temperature of various areas of their homes. This can be done only if you have enough alcohol thermometers so that each student has his own. The alcohol thermometers recommended for this course are relatively inexpensive. In quantities of 100 or more, the cost should be about fifteen cents each.

Students may want to use their thermometer to measure the temperature of various liquids. This could be hazardous. We suggest that students check with you before experimenting with any substance not listed in the student edition.

INVESTIGATION 10.4: Behavior of Matter at Low Temperature *(Optional)*

(pages 252–253)

Dry ice is the coldest substance readily available to most schools. Technical difficulties limit the use of liquid nitrogen and other cryogens at either the elementary or high school level.

This investigation will demonstrate how matter behaves at the extremely low temperature of dry ice (which ranges between −75° and −79°C, depending upon atmospheric pressure).

You may find it convenient to do this investigation as a demonstration in connection with the Inquiry Demonstration which follows it.

MATERIALS

Ordinary glass containers are likely to break under these extremely cold conditions. Substitute Pyrex beakers or metal containers wrapped with insulating material.

Dry ice may be ordered from a local ice-cream distributor. Ten pounds should be sufficient for five classes.

PROCEDURES

A.–B. No comment.

C. We have found that alcohol thermometers at room temperature do not break when put in dry ice. However, precooling is recommended as a safeguard. Students should obtain readings ranging between −70° and −80°C.

D. If Ditto fluid remains in dry ice long enough, it will freeze. Little change in volume occurs when Ditto fluid is frozen. It is impossible to freeze Ditto fluid in an ordinary refrigerator.

INTERPRETATIONS

1. *a.* Change in volume of Ditto fluid is very slight. Change in volume of water is about ⅛.
   b. Water freezes at 0°C; dry ice at −78°C.
2. Dry ice is solid carbon dioxide. Carbon dioxide molecules are nonpolar and have little attraction for each other. Ordinary ice forms at a much higher temperature because of the greater attractive forces between the polar water molecules. This accounts for the extremely low temperature of dry ice.
3. Salt is often sprinkled on snow covered roads to lower the freezing point of water in an attempt to prevent the formation of ice. Alcohol is an ingredient of antifreeze.

INQUIRY DEMONSTRATION: Quick Freezing

(Teacher Only)

If crushed dry ice is slowly added to acetone until active bubbling ceases, the temperatures of the acetone and dry ice will be about equal. Vegetable material, frankfurters, soft rubber balls, and other materials freeze almost instantly when placed in this liquid. The temperature of the mixture is about equal to that of dry ice alone, but the contact area offered by the liquid is, of course, greater. Hence the rapid rate of cooling results.

MATERIALS

Pyrex beaker, 250 ml
Acetone, 2 pints
Dry ice
Tongs or pliers
A few common vegetables, banana, frankfurter
Soft rubber ball
Hammer

PROCEDURES:

CAUTION: *Acetone is highly flammable. Keep away from flame or hot plate. Carry out the demonstration in a well-ventilated room and avoid inhalation of fumes. If dry ice is added too rapidly, a vigorous reaction causes splattering of the acetone. Fingers will freeze quickly if immersed in the acetone and dry ice mixture.*

A. Pour acetone into the beaker until the beaker is about half-full.
B. Very slowly add crushed dry ice until bubbling ceases.
C. Use metal tongs or pliers to immerse the various objects, one at a time, in the acetone. Remove and allow the class to observe the following:
   1. A frozen ball will not bounce.
   2. If a frozen frankfurter or vegetable is struck with a hammer, it will shatter.

The Nature of Heat: A Problem

You have now worked with temperatures ranging from about 100°C to far below 0°C. When water reaches a certain temperature, it boils; and if this temperature is maintained, the water will soon "disappear." When water is kept between 100°C and 0°C, it will remain in a liquid phase, with only very slow evaporation taking place. The higher the temperature, the greater the rate of evaporation. If we lower the temperature of water to 0°C, it begins to freeze. As you have seen, ice has properties quite unlike those of water. If ice is left outdoors even in subzero temperature, it too may slowly change to vapor. After examining Figure 10 • 11, think of a model to explain the different stages in the evaporation of water.

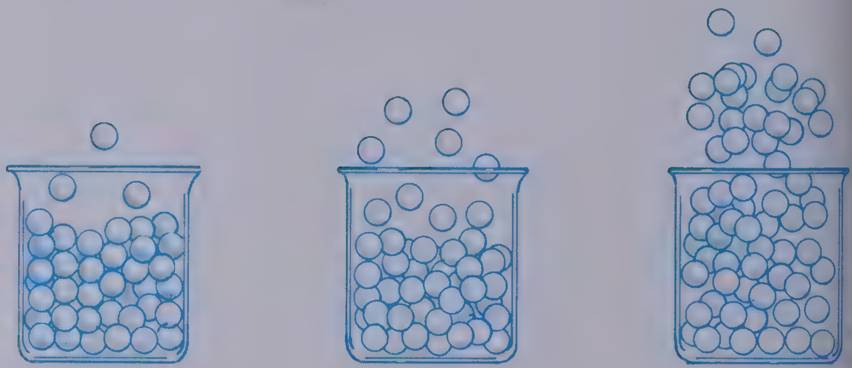


Figure 10 • 11. Diagrammatic drawing of the different stages in the evaporation of water.

Your problem is to explain heat in terms of the experiments you have performed. What relationship exists between heat and the behavior of water molecules? Base your explanations on the behavior of molecules, the behavior of demons, or some other theory. Be prepared to defend your argument. Prepare a model as part of your explanation of heat. How useful your model will be depends on how well you have studied previous parts of this course and upon how ingenious you are in putting your knowledge to work.

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The Nature of Heat: A Problem

(page 254)

The concept of energy will be presented in more detail in later sections. We have gradually introduced the function of energy, and by now students should be able to use the concept of energy to explain events they observe.

Students should now understand that there are at least three phases of matter: solids, liquids, and gases. The problem concerning the nature of heat is presented as a challenge to students to explain the relationship of heat to the structure of matter in these phases. It is hoped that students will devise models that indicate the *kinetic properties of matter,* even though they may not use this terminology.

Students have observed a solid (ice) changing to a liquid when heat was applied. When heat was applied to water (Investigation 10.1), the water turned to gas. From these observations it is hoped students will see that the rate of motion of particles is directly related to the phase in which matter occurs.

SUPPLEMENTARY MATERIALS

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FILM

Physics and Chemistry of Water. Film Associates. 21 minutes. Color. This film illustrates and discusses the remarkable characteristics of water. It includes evaporation, surface tension, polar molecules, hydrogen bonding, and temperature effects. Show at completion of this section.

SUGGESTED ACTIVITIES FOR TESTING LABORATORY SKILLS AND TECHNIQUES

INVESTIGATION 10.1

Divide a given distance into halves and quarters.
Divide a given distance into tenths.
Interpolate on a thermometer scale.

INVESTIGATION 10.3

Extrapolate on a thermometer scale.
Measure the temperature of a sample of water.
Calibrate a thermometer.

SECTION ELEVEN

Heat Energy

SECTION ELEVEN

Heat Energy

(pages 257–276)

Preview

One of the most confusing concepts for many students to understand is the difference between temperature and heat energy. The two are quite different.

In Section Ten, students learned how to measure the *temperature* of various substances. Thermometers are useful in measuring and comparing the temperature of matter. But temperature is not meaningful without an understanding of heat energy.

Students are gradually introduced to evidence supporting a kinetic model to represent heat energy. They compare the capacity of different phases of matter to store heat. They examine the relationship between the different numbers and kinds of atoms present and the amount of heat energy stored. By investigation, they determine some of the factors which control heat transfer and storage, and the rate and direction of heat flow. They also collect data which illustrates the difference between heat energy and temperature. Students should see the relationship between temperature changes and changes in molecular movement. Data will also indicate the conservation of heat energy as calculations are made to account for heat transfer.

During Investigation 11.1, students vigorously shake a jar of water and learn that their own energy can cause a rise in water temperature. Following the investigation the terms *calorie* and *kilocalorie* are introduced and their meanings explained.

An "On Your Own" investigation follows. Students are asked to touch the sides of their noses with a cool metal jar lid. The lid should feel cold compared to the sides of their noses. After they vigorously rub the lid on their clothing and touch their noses, they should notice that the jar lid and their noses appear to be about the same temperature. Students are asked to explain this phenomenon in terms of the kinetic model of heat.

During Investigation 11.2, "Heat Storage," students calculate heat energy in calories and learn more about the difference between heat and energy. An "On Your Own" investigation follows Investigation 11.2, during which students are asked to repeat the experiment with several different metals. For very observant students this should lead to the concept of specific heat of metals in relation to their atomic weights. It is recommended that more advanced students undertake this additional investigation on an individualized study basis. However, all students should be given an opportunity to carry out the investigation if they wish.

Investigation 11.3, "Heat and Temperature," is designed to help students further understand the difference between heat and temperature. Their ability to calculate heat in terms of calories will be important in completing this investigation.

Additional Investigations, 11.4 through 11.7 allow students to investigate the nature of heat and the kinetic model for heat. They include a study of: heat and volume (Investigation 11.4), heat and molecular attraction (Investigation 11.5), heat flow (Investigation 11.6), and color and heat (Investigation 11.7).

PLANNING AHEAD

Please read through the section to make sure you have the materials on hand for each investigation.

LEARNING OBJECTIVES

Given the opportunity to inquire, to investigate, to interpret data, and to offer hypotheses about the activities in this section, most students should be able to—

- Demonstrate heat flow;
- Describe some of the early models of heat energy;
- Develop a model to explain temperature increase in water after agitation or shaking;
- Offer a model which accounts for differences in the heat storage capacity of different kinds of matter (water, lead, aluminum, iron, etc.);
- Interpret data from a series of investigations to explain the difference between temperature and heat energy;
- Explain conservation of heat energy using the concepts of heat storage, heat transfer, and changes in state;
- Include the conservation of energy in their model for the behavior of matter;

- Calculate the calories lost or gained when a sample of water changes temperature;
- Observe, describe, and explain the effect on volume of adding heat energy to a sample of water;
- Describe a model which explains the relationship between changing temperatures and possible changes in molecular movement;
- Develop hypotheses which explain evaporation, molecular attraction, heat transfer, and heat storage;
- Explain the role of evaporation in reducing the average molecular energy of motion;
- Demonstrate the difference that color can make in the rate that heat can be absorbed by a body;
- Use various laboratory devices to measure temperature and the amount of heat energy transferred from one sample of matter to another.

Early Greek writers believed that heat is a substance and that it moves from a hot object into a cold object. This model of heat was used by most scientists for many centuries. In the early eighteenth century, several scientists developed the concept that heat is a fluid that flows freely from one object to another. This fluid was named *caloric.* It was thought that an atom of any substance is surrounded by caloric fluid. According to this model, if an object is heated, the spaces between its atoms will be filled with more caloric. An object with lots of space between its atoms will hold more caloric than an object that has little space between its atoms. The caloric model was a success because it explained all the observations of heat made up to that time.

The development of reliable thermometers during the eighteenth century made it possible to conduct experiments involving fairly precise temperature measurements. In 1714, the German physicist Gabriel Fahrenheit made a mercury thermometer and developed the Fahrenheit temperature scale. On the Fahrenheit scale, 32° is the freezing point of water and 212° is the boiling point of water. In 1742, the Swedish astronomer and physicist Anders Celsius devised a temperature scale on which 0° is the freezing point of water and 100° is the boiling point. This became known as the *centigrade* scale—from Latin and French words meaning "hundred steps." By an agreement at an international conference of scientists in 1948, it was decided that the centigrade scale be called the *Celsius* scale. The Celsius and Fahrenheit scales are compared in Appendix C, at the back of the book.

Benjamin Thompson, later known as Count Rumford (1753–1814), was interested in the nature of heat. Rumford owned one of the most precise balances available in the eighteenth century. He weighed water and other substances before and after heating and cooling them. In his experiments, he could find no evidence that any fluid enters an object during heating or leaves it during cooling. For example, he noticed that a cannon became very hot while the barrel was being bored. He could find nothing, however, to indicate that the boring added anything to the metal. In-

stead he suggested that heat results from the motion of particles. As matter is heated, the speed of its particles increases; as matter is cooled, the particles slow down. According to this theory, heat is a form of energy. Today we call this theory the *kinetic* theory of heat.

In the next series of investigations, you will examine various characteristics of heat. As you complete them, you should attempt to explain results in terms of the kinetic theory of heat. At the end of each investigation, be prepared to explain the effects of heat in terms of the motion of molecules.

INVESTIGATION 11.1: Energy Transfer

Your present understanding of force and energy may be different from what it was when you started this course. You should have learned the difference between kinetic energy and potential energy and how one can be converted to the other.

There are many ways in which potential energy can be converted to kinetic energy. The most familiar source of energy to you, though you may not have thought of it this way, is the food you eat. In this investigation, *you* will provide the source of potential energy. Your muscles will convert some of the potential energy in the food you have eaten into kinetic energy—energy of motion. You will observe the effect of transferring this energy to a sample of water.

MATERIALS (per team)

Graduated cylinder
Glass jars with screw lids, 2
Thermometer
Newspaper
Tape

PROCEDURES

A. Pour 20 ml of water into each of the two glass jars. Record the water temperatures. Use one of the alcohol thermometers calibrated in Section Ten and mark the initial level of the alcohol with a piece of tape on the stem of the thermometer.

B. Tighten the lids on the jars. Wrap both jars in newspaper, as shown in Figure 11 • 1. When you are finished, the jars will be wrapped in at least eight thicknesses of paper. The paper will act as a heat insulator.

C. Shake one jar vigorously (about four times per second) for four minutes. Members of the team may take turns doing this so that the shaking continues at a rapid pace. In shaking the jar, move it less than 2 inches, back and forth. Do not shake the second jar.

D. Unwrap the jars. Remove the lids and again record the temperature of the water in each.

INTERPRETATIONS

1. Calculate the temperature change (if any) in each jar and record in your notebook. You have learned how units for measuring length, volume, and mass developed. You have used

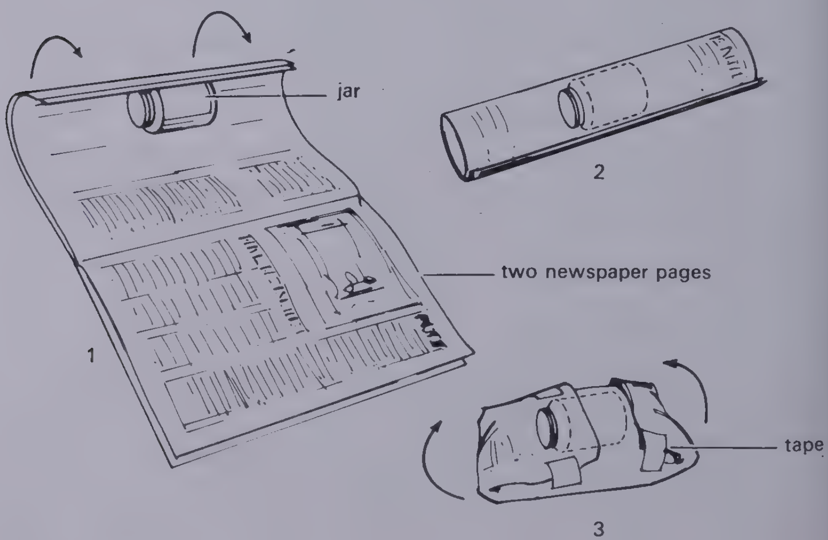


Figure 11 • 1. Carrying out Procedure B.

other units to measure temperature (usually degrees Celsius or degrees Fahrenheit). The unit for measuring heat energy is the *calorie*. One calorie is the amount of heat energy required to raise the temperature of 1 g of water 1°C. How many grams of water did you place in each jar? How many calories were gained by the water in each jar?

2. Using the kinetic theory of heat, explain any temperature changes you observed.

Scientists often measure heat in *kilocalories* when dealing with larger amounts of heat. The kilocalorie is the amount of heat energy required to raise the temperature of 1 kilogram of water 1°C. Thus the kilocalorie is equal to 1000 calories. The kilocalorie is often abbreviated as *Calorie* or *Cal.*, with a capital *C*. The familiar calories used in measuring the energy content of foods are kilocalories (Calories).

PROBLEMS

1. How many calories will be needed to raise the temperature of 50 g of water from 5°C to 85°C?
2. One kilogram of water was cooled from its boiling temperature (at sea level) to freezing. How many calories were lost by the water?

ON YOUR OWN: Transferring Motion

This investigation should be performed after school or at home. All you will need is a metal lid from a jar. The jar lid should be cool—about room temperature.

First, place the top side of the lid against one side of your nose. Record the sensation you feel. Which feels warmer, the jar lid or your nose? Next, *vigorously* rub the top part of the lid on your clothing for about thirty seconds. Which feels warmer, the lid or your nose? Record the answers to both questions, in your notebook. Try to explain your observations in terms of the kinetic model of heat.

INVESTIGATION 11.1: Energy Transfer

(pages 259–261)

The purpose of this investigation is to demonstrate (qualitatively) that kinetic energy can be used to raise the temperature of a substance. It should provide data useful in kinetic theories of heat.

MATERIALS

Baby-food jars are recommended. The water should be cooler than room temperature to start with.

PROCEDURES

A. Use standard laboratory thermometers, if they are available. The scale that the student marked on his alcohol thermometer (Investigation 10.1) may not be precise enough to permit accurate readings. If alcohol thermometers are used, changes in temperature may be detected when the initial level of the alcohol is marked with tape.

B. No comment.

C. Students may need to take turns shaking the jar to keep it continuously in motion. The heating effect may be enhanced if students hit the bottom of the jar against the palm of their empty hand.

D. No comment.

INTERPRETATIONS

1. A 4°C temperature change is typical. For 20 g of water this temperature change requires 4×20, or 80, calories. The number of calories equals the number of grams of water times the number of degrees (C) change in temperature. Stress that *every measurement is, in a sense, an estimate*. The precision of an estimate depends partly on the device used and partly on the estimator. Results will probably vary in this investigation, because it is very unlikely that any two groups will add the same amount of energy to the water when shaking it.
2. It is impossible to explain how any "caloric substance" (p. 258) could have entered the jar that was shaken. Shaking certainly did cause motion of water molecules. If some of the molecules continue to move with more speed after the shaking than they did before, and if temperature is a measure of the average kinetic energy of the molecules, then the increase in temperature is a logical result. Therefore, the result is in agreement with the kinetic model of heat.

Continue to emphasize the relationship between calories of energy and degrees of temperature change. Stress that calories are by definition units for measuring the amount of heat energy necessary to produce a given temperature change in a specified amount of matter. If a substance other than water is used, 1 calorie of heat energy may change the temperature of 1 g of the sample by quite a different amount. Students will examine this concept in the next investigation. For a discussion of heat, see Rogers,[T1] pp. 412–414, or Holton and Roller,[T2] pp. 324–360, but avoid discussion of the points raised in the next six investigations until the work is done.

PROBLEMS

1. The number of calories gained is equal to the number of grams of water times the number of degrees (C) change in temperature.
   Number of calories = 50 × 80 = 4000 calories gained.
2. Water boils at 100°C and freezes at 0°C. One kilogram is equal to 1000 g.
   Number of calories = 1000 × 100 = 100,000 calories lost.

ON YOUR OWN: Transforming Motion

(page 261)

The student should find that the jar lid feels quite cold when first placed against his nose. After rubbing the lid vigorously for thirty seconds or more, the lid and nose should give the sensation of about equal warmth. Student explanations of this phenomenon in terms of the kinetic theory may vary. Please accept all answers as possible at this time since some students may find the kinetic model difficult to grasp. With additional investigation, the kinetic model should become more realistic.

A variation of this investigation is for the student to place the jar lid in the palm of his hand. After about thirty seconds, the lid and the side of his nose should appear equally warm.

A side question you may wish to ask is, "How soon does the jar lid return to its original temperature after rubbing it on clothing?" Only a few seconds will elapse before this occurs. Ask, "Why, in terms of kinetic energy, does this rapid cooling of the lid occur?"

[T1] Eric Rogers, *Physics for the Inquiring Mind* (Princeton, N.J.: Princeton University Press, 1960).

[T2] Gerald Holton and Duane Roller, *Foundations of Modern Physical Science* (Reading, Mass.: Addison-Wesley Publishing Co., 1958).

INVESTIGATION 11.2: Heat Storage

We have defined a calorie as the amount of energy required to raise the temperature of 1 g of water 1°C. Water can store heat energy. Other liquids, as well as metals, can also store heat energy. But different materials have different capacities for heat storage. The heat-storing capacity of equal weights of water and a metal will be compared during this investigation. Before performing the investigation, predict which has the greater heat-storing capacity—a metal or water.

MATERIALS (per team)

Styrofoam cups, 2
Graduated cylinder
Balance, sensitive to 1 g
Thread
Metal weight
Pyrex beaker
Burner
Thermometer

PROCEDURES

A. Label the Styrofoam cups *A* and *B*. Pour 40 ml of tap water into each cup.
B. Using the balance, determine the weight of the metal to the nearest gram. Tie a 10-inch length of thread to the metal. Weigh out an amount of tap water equal to the weight of the metal. Record the weights of the metal and the water.
C. Place the metal object and water from Procedure B in a beaker and heat to about 80°C. (Allow the thread attached to the metal to hang over the edge of the beaker.)
D. Copy Figure 11 • 2 in your notebook. Measure the water temperature in Cups A and B and enter the data in the table.
E. When the temperature of the water has reached 80°C, transfer the metal to Cup A and pour the hot water into Cup B. Stir the contents of both cups for one minute. Then record the water temperature in each cup.

Figure 11 • 2.

	Before Metal Is Added	*One Minute after Metal Is Added*
Cup A temperature		

	Before Hot Water Is Added	*One Minute after Hot Water Is Added*
Cup B temperature		

INTERPRETATIONS

1. How many calories did the 40 ml of cool water in Cup A gain?
2. How many calories did the 40 ml of cool water in Cup B gain?
3. Which contains more heat energy—metal at 80°C or an equal weight of water at 80°C?
4. According to kinetic theory, what is the relationship between temperature and molecular motion?
5. According to kinetic theory, what is the relationship between heat and molecular motion?
6. If two samples have the same temperature, how could they contain different amounts of heat?
7. Using the kinetic theory of heat and what you have learned about the structure and behavior of matter, explain your answer to Interpretation 3.

ON YOUR OWN: Molecular Momentum?

Perform this investigation during class, after school, or at home. While this investigation is more difficult than some of the others, you may discover an important principle of physical science.

Repeat Investigation 11.2 using other metals such as aluminum, copper, iron, zinc, or brass. Make the necessary calculations to see if your data supports your answer to Interpretation 7. What does this information have to do with momentum?

INVESTIGATION 11.2: Heat Storage

(pages 262–263)

Comparing the heat stored in equal weights of metal and water should help students to realize the difference between heat and temperature.

MATERIALS

The lead should weigh about 40 g. A *large lead fishing weight is ideal.* Other metals such as aluminum, brass, copper, iron, or zinc may be used. The pieces should be thick, so they will not cool too rapidly as they are transferred from one container to the other. Folded aluminum foil can be used, but it may carry enough hot water with it to cause considerable error. Large iron (or steel) nuts work nicely. If a variety of metals is assigned to teams, students can compare the capacity of heat storage (specific heat) of different metals. We recommend that lead be included as one of the metals because of its low specific heat.

If regular laboratory thermometers are not available, the alcohol thermometers calibrated by the students in Investigation 10.1 will be adequate.

PROCEDURES

A. If metals other than lead are used, it may be necessary to use more water. There should be enough water in each cup to completely cover the metal.

B. Students should recall the relationship between the weight and volume of water (1 g of water = 1 ml) from Investigation 7.3.

C.–D. No comment.

E. The purpose is to compare the amount of heat lost by equal weights of water and metal at the same temperature when they are transferred to cooler water. The weights of the hot water and of the hot metal as well as their initial and final temperatures are determined by the students. Sample data appear in Figure T-11 • 1.

Figure T-11 • 1.

	Before Metal Is Added	*One Minute after Metal Is Added*
Cup A temperature	20°C	22°C
	Before Hot Water Is Added	*One Minute after Hot Water Is Added*
Cup B temperature	20°C	50°C

INTERPRETATIONS

1. The cool water in Cup A gains 40 g $\times$ 2° = 80 calories.
2. The cool water in Cup B gains 40 g $\times$ 30° = 1200 calories.
3. The water in Cup B will register a higher temperature than the water in Cup A. This indicates that at a given temperature, water stores a greater amount of heat energy than does an equal weight of metal.
4. The present kinetic theory of heat assumes that temperature is a measure of the *average* kinetic energy of the molecules present.
5. The amount of heat is determined by (or is equal to) the total kinetic energy of the molecules.
6. The average kinetic energy per molecule is determined by dividing the total kinetic energy by the number of molecules present. If two samples contained different numbers of molecules, they could have the same temperature but different amounts of heat.
7. A mole of one element contains the same number of atoms as does a mole of any other element. Thus, a mole of water contains the same number of molecules as 1 mole of a metal, such as lead. Water weighs 18 g/mole, and therefore 1 g of water is $1/18$ of a mole, or about 0.05 mole. Since 1 mole of lead weighs 208 g, 1 g of lead is $1/208$ of a mole, or about 0.005 mole. Thus 1 g of water contains approximately ten times as many molecules as does 1 g of lead.

   When water and metal are at the same temperature, the kinetic energy *per molecule* is the same in each substance. (This is another way of saying that the *average* kinetic energy of the molecules in each substance is the same.) Since a given weight of water contains more molecules than an equal weight of lead, water can store more heat than the lead when both are at the same temperature.

ON YOUR OWN: Molecular Momentum?

(page 263)

This activity illustrates the theoretical basis for the law of Dulong and Petit, which states that the specific heats of the elements are inversely proportional to their atomic weights. If the teams have used different metals, they should be able to see the relationship between atomic weights and the amount of heat stored by each at the same temperature. Aluminum, iron, and copper give results quite different from those obtained with lead.

Specific heat is the number of calories required to raise 1 g of a substance 1°C. We see no good reason to require your students to memorize a definition for specific heat. However, an understanding of relationships between temperature and heat content is necessary to an understanding of the kinetic theory of heat.

The following list of specific heats of some common metals may be useful:

Aluminum	0.208
Copper	0.092
Gold	0.031
Iron	0.107
Lead	0.031
Silver	0.056
Tin	0.054
Zinc	0.092
Brass	0.092

INVESTIGATION 11.3: Heat and Temperature

Nearly everyone has used ice to cool something. This investigation should help you predict the cooling effect of a given amount of ice. It may also help you to understand more about the difference between heat and temperature.

MATERIALS (per team)

Ice, about 60 g
Graduated cylinder, 100 ml (heat-resistant plastic or Pyrex)
Styrofoam cups, 2
Balance sensitive to at least 0.1 g
Pyrex beaker, 250 ml
Ring stand, ring, and wire gauze
Burner
Ice and water in large container
Thermometers, 2
Small spoon or mixing stick

PROCEDURES

A. Label the Styrofoam cups *A* and *B*. Periodically stir the ice and cold water.
B. Weigh Cups A and B. Record the weights in your notebook.
C. Pour 200 ml of tap water into a beaker and heat to boiling. While the water is heating, complete Procedures D, E, and F. When the water starts to boil, turn off the heat and set the beaker of hot water aside for use in Procedures G and H.
D. Pour 40 g of water from the ice-and-water mixture into Cup A.
E. Place Cup B on the balance and add about 20 g of ice. The amount added should be weighed as accurately as possible. Record the weight of the ice in your notebook. Pour water from the ice-and-water mixture into Cup B until there is a total of 40 g of ice and water in Cup B.
F. Record the temperature of the contents of Cups A and B.

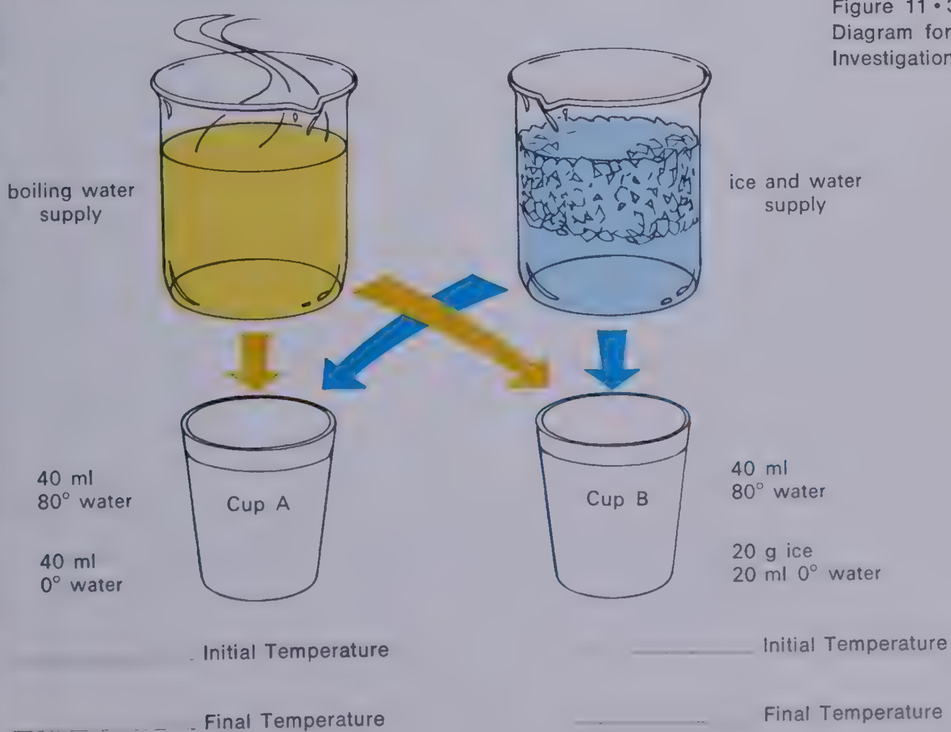
G. Wrap a folded paper towel around the beaker of hot water so you can pick it up without burning your hand. Pour 40 ml of hot water into a graduated cylinder and place a thermometer in the water. When the temperature has fallen to 80°C, pour the water into Cup A. Stir the mixture carefully for several seconds with a spoon or mixing stick. Record the temperature of the mixture in your notebook.

H. Pour another 40 ml of hot water into the graduated cylinder. When it has cooled to 80°C, pour it into Cup B. Again stir the mixture carefully. As soon as all of the ice has melted, measure the temperature of the mixture and record it in your notebook.

INTERPRETATIONS

1. Compare the final temperatures in Cups A and B. Why are they different?
2. Remember that three phases of matter are solids, liquids, and gases. Predict what would happen to the temperature of boiling water if you added heat energy to it.

Figure 11 • 3. Diagram for Investigation 11.3.



PROBLEMS

1. In Procedure G, how many calories of heat were lost by the hot water as it cooled from 80°C to the final temperature of the mixture? Remember that 1 calorie is lost by each gram of water for each degree of cooling.
2. In Procedure G, how many calories were gained by the water in Cup A?
3. In Procedure H, how many calories were lost by the hot water after it was poured into Cup B?
4. In Procedure H, how many calories were gained by the ice-and-water mixture in Cup B?
5. How many calories were needed to change each gram of ice to liquid in Procedure H?
6. One pint is equal to approximately 500 ml. If you place a pint of water—at 20°C—in the freezing compartment of a refrigerator, how many calories of heat must the water lose before it is frozen?

INVESTIGATION 11.3: Heat and Temperature

(pages 264–266)

In this investigation students should discover how the amount of heat needed for a phase change compares with the amount needed to produce a 1 degree temperature change for a sample of water. They should also use this information to modify the meaning of heat and temperature in their model for the structure and behavior of matter.

MATERIALS

Allow for at least 60 g of ice per team since some melting will occur in cooling the water to 0°. To save time, mix the water and ice for the whole class instead of having each team prepare the mixture as described in Procedure A. Also, it may save time and be safer if you heat the water for the whole class instead of having them follow Procedure C. Each team will use about 40 ml of hot water, but plan for loss due to evaporation and spillage.

PROCEDURES

A. The exact proportion of ice and water is not critical, but there must be enough ice to cool the water to 0° and still leave at least 20 g unmelted.

B.–D. No comment.

E. It is not critical that precisely 20 g of ice be weighed out, but the closer the better. Students should know the weight of the ice in the beaker and record it. They should then add enough water to make the total weight of the mixture 40 g.

F. No comment.

G. Show students how to use the paper towel to prevent burning their hands. Although the temperature of the hot water need not be exactly 80°C, the procedure should yield a final temperature near that of the room. If the temperature of the hot water is below 80°C, some of the ice will not be melted, and the melting process may be rather slow.

H. No comment.

INTERPRETATIONS

1. Considerable heat energy is required to change ice to water. Approximately 80 calories are needed to change 1 g of ice at 0°C to water at 0°C. The temperature of the ice and the ice water would be the same. The energy (heat) content of equal weights of the two would be quite different.

2. A change similar to the change from solid to liquid phase occurs when water is changed to vapor. Approximately 540 calories are required to convert 1 g of water at 100°C to 1 g of vapor at 100°C. Therefore, as more heat energy is added to boiling water, temperature does not change, but the vapor formation rate increases.

   When 1 g of vapor condenses to form water, the same amount of energy is released—that is, about 540 calories per gram.

PROBLEMS

The problems are based on the assumption that the temperature of the hot water was 80°C just before it was added to the cold water or to the ice-water mixture. If students used hot water at different temperatures, have them substitute their recorded temperature of the hot water for the 80°C in Problems 1 and 3.

1. If you used 40 g of water at 80°C, the final temperature should be about 40°C. The number of calories lost by the hot water would be $(80-40)40 = 1600$.
2. If the amounts of cold and hot water were each 40 g, then the amount of heat gained by the cold water will be $(40-0)40 = 1600$ calories. Even if the amounts of hot and cold water were not equal, the number of calories gained by the cold water should be equal to the number of calories lost by the hot water.
3. Final temperature should have been about 20°C. Calories lost by the hot water would be $(80-20)40 = 2400$ calories.
4. As was pointed out in Problem 2, the amount of heat lost by the hot water should be equal to that gained by the cold water and the ice; but here the temperature of the ice-water mixture rose only about 20°, while the temperature of the hot water was lowered 60°.
5. Some of the heat warmed the water from 0°C to 20°C, and some caused the phase change from ice to water. The amount of heat needed to change the water (after the ice melted) from 0°C to 20°C is $(20-0)40 = 800$ calories. The remaining calories were lost in accomplishing the phase change (20 g of ice to water).

$$2400-800 = 1600 \text{ calories}$$

$$\frac{1600 \text{ cal}}{20 \text{ g}} = 80 \text{ cal/g}$$

6. First the water must lose 20×500, or 10,000, calories in cooling from 20° to 0°C. Then it must give up 80×500, or 40,000, calories in changing from the liquid to the solid state. The total heat loss must be 10,000 calories plus 40,000, or 50,000, calories. Therefore, the refrigerator must remove that number of calories from the water if all the water is to be frozen.

INVESTIGATION 11.4: Heat and Volume

According to the kinetic model, heat is related to the motion of molecules. When heat is added to a sample of matter, the molecules in that sample move faster. Do you suppose that molecules in a liquid and molecules in a gas will respond in the same way to the same amount of heat?

MATERIALS (per team)

- Glass tubing (about 60 cm)
- Flask, 250 ml with 1-hole stopper
- Metric ruler
- Burner

PROCEDURES

A. Insert the glass tubing into the hole of the stopper so the tubing will extend about halfway into the flask when the stopper is in position.

B. Put a drop of water in the glass tubing and let it move down the tubing until it is near the top of the stopper (Figure 11 • 4). Stop the drop by placing a finger over the top end of the glass tubing. Keep your finger on the tubing and seal the

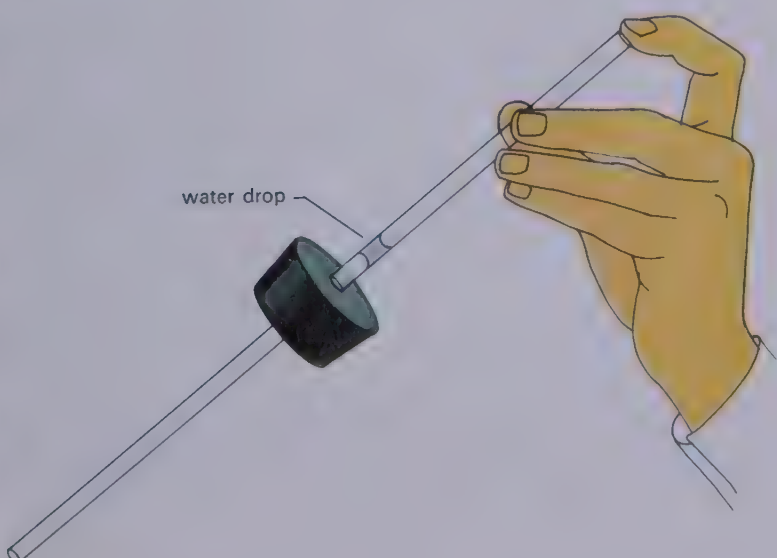


Figure 11 • 4. Beginning Procedure B.

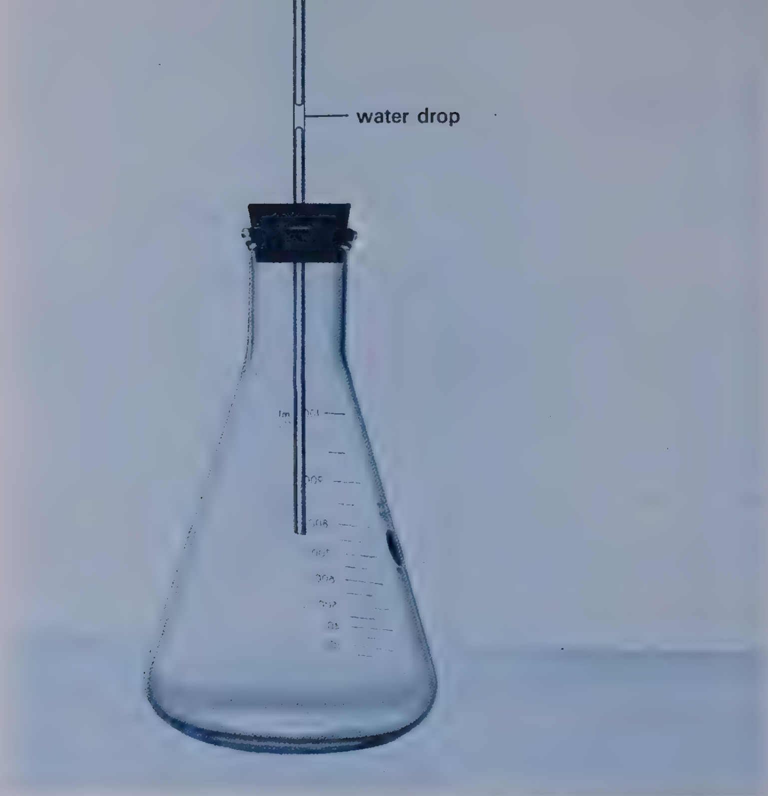


Figure 11 • 5.
Completed setup for Procedure B.

flask with the stopper. Adjust the position of the drop by pushing down or pulling up on the stopper, so that the bottom of the drop is slightly above the stopper (Figure 11 • 5).

C. Measure and record the distance between the top of the stopper and the drop.

D. Wrap your hands around the flask for several seconds. Measure and record any change in the position of the water drop.

E. Blow the water droplet out of the glass tube. Remove the stopper and fill the flask to the brim with water. Insert the stopper into the flask, allowing excess water to spill out. Push the stopper down until the level of water in the glass tube is about 20 cm above the top of the stopper. The stopper should fit firmly in place (Figure 11 • 6).

F. Measure and record the height of the water above the stopper.

G. Wrap your hands around the flask and hold for one minute. Then quickly measure the height of the water column. Record any change in your notebook.

H. Using the burner, gently heat the flask of water for several seconds. Again measure and record any change in the height of the water column.

Figure 11 • 6.
Setup for
Procedures E–H.

INTERPRETATIONS

1. In Procedure D, what was responsible for the movement of the water drop?
2. Compare the movement of the water drop in Procedure D with the movement of the water column in Procedures G and H. Remember that molecules in a gas are far apart and attract each other very little, while molecules in a liquid are close together and thus have stronger attraction for each other. Explain the behavior of the water in the glass tube in Procedures D, G, and H by using the kinetic theory of heat.

FOR CLASS DISCUSSION

1. For what other purpose might you use the tube and flask apparatus?
2. Name several practical applications of heat energy applied to a gas or a liquid. These applications should involve the same types of behavior you have observed in this investigation.

INVESTIGATION 11.4: Heat and Volume

(pages 267–269)

Students should observe that the change in volume for a liquid is much smaller than the change in volume for a gas when the same amount of heat is added. They should interpret this as evidence that molecular attractions are much smaller in a gas than in a liquid. If you are pressed for time, you may want to perform the investigation as a teacher demonstration.

MATERIALS

The glass tubing should fit snugly in the stopper to prevent air leaks.

PROCEDURES

A. No comment.

B. Enough water should be placed in the glass tube to form a drop about 1 cm long. Students may have difficulty keeping the drop at the desired position in the tube. When the stopper (with tube) is inserted into the flask, air trapped in the flask will force the drop to rise as soon as the finger is removed from the end of the tube.

C. No comment.

D. The drop of water should rise very rapidly.

E.–F. No comment.

G. The water column should rise slightly.

H. The water column should rise about 3 or 4 cm, or even more if the water becomes quite warm.

INTERPRETATIONS

1. Heat from the students' hands caused the air in the flask to expand.
2. In Procedure D the drop moved very rapidly and nearly the length of the tube. The column of water moved slowly and through a much smaller distance. The difference in behavior arises from the difference in the degree of attraction between molecules in a gas and molecules in a liquid.

   According to our model of the structure of matter, molecules in a gas are far apart and attract each other very little. And according to the kinetic model of heat, the average speed of molecules increases with temperature. The faster the motion of gas molecules, the more often they will hit the sides of the container, and the greater will be the pressure. If one surface is free to move (as in this investigation), the volume will increase until the pressure inside the container equals the pressure outside the container.

Molecules of a liquid have a much stronger attraction for each other than do molecules of gas. (Relate this to the students' observations of the behavior of drops, films, and bubbles in Investigations 2.2 and 2.3.) This restricts the movement of molecules of a liquid. Thus the change in volume caused by a change in temperature is much less in a liquid than in an equal volume of a gas.

FOR CLASS DISCUSSION

1. It could be used as a crude thermometer. The apparatus would have to be calibrated between fixed temperatures, as was done earlier with the alcohol thermometers. You might wish to expand upon this idea. For example, which apparatus—the one used in Procedure B or the one used in Procedure E—would be most sensitive to a change in temperature? What advantages and disadvantages would these kinds of thermometers have in comparison with regular laboratory thermometers?

   One of the earliest thermometers was a gas thermometer devised by Galileo near the close of the sixteenth century. It was not different in principle from the one used here. (See Bonner and Phillips,[T3] p. 221, and Asimov,[T4] pp. 323–325.)

   Of course the gas thermometer would be more sensitive to changes in temperature than would either of the two flask-and-tube apparatus observed in this investigation. For great temperature differences a very long tube would be needed, or the capacity of the flask would need to be reduced. The major difficulty with this thermometer (and with Galileo's) is that the pressure of the atmosphere changes from day to day, which necessitates recalibrating the thermometer each time there is a change in barometric pressure.

   The water thermometer was also used in early times. But since other materials (such as alcohol) expand more than water when they are heated, and others (such as mercury) are more easily seen in the capillary tube, they are more commonly used in thermometers today. Since water freezes at an easily attainable temperature (0°C), it cannot be used for measuring low temperatures.
2. A few examples include heating air under large balloons to inflate them, creating steam pressure by heating water in a closed system, internal combustion engines, and thermometers. Students should be encouraged to think of as many practical applications as possible.

[T3] Francis Bonner and Melba Phillips, *Principles of Physical Science* (Reading, Mass.: Addison-Wesley Publishing Co., 1957).

[T4] Isaac Asimov, *The New Intelligent Man's Guide to Science* (New York: Basic Books, 1965).

INVESTIGATION 11.5: Heat and Molecular Attraction

You have gained some evidence that molecules attract each other. The behavior of water drops and soap films was the first such evidence you observed, in Section Two. Investigation 11.5 will give you a chance to use the kinetic model to compare attractions between molecules for two different substances.

MATERIALS (per team)

Cotton cloth (1 x 4 inches), 3 pieces
Rubber bands
Ditto fluid (alcohol), 20 ml
Beakers, 2
Thermometers, 3

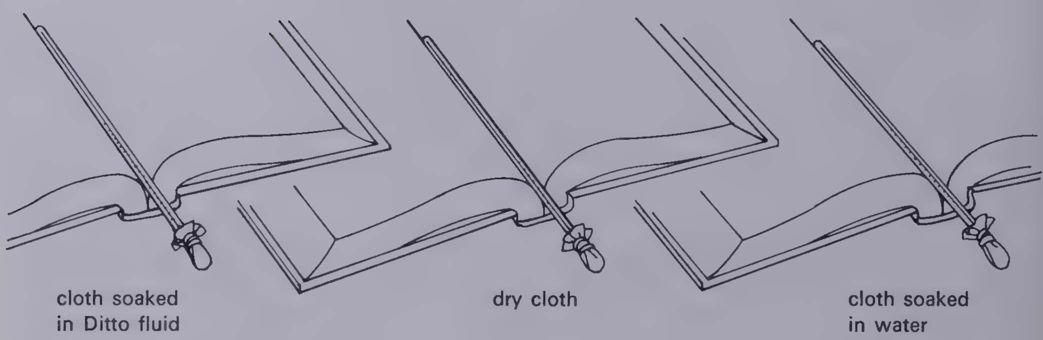
PROCEDURES

A. Soak one piece of cloth in the Ditto fluid, soak the second piece in water, and leave the third piece dry.

B. Remove the piece of cloth from the water, let it drip for about thirty seconds, and wrap it around the bulb of a thermometer. Repeat with the piece of cloth from the Ditto fluid, using the second thermometer. Wrap the dry cloth around the third thermometer. Fasten each cloth with a string or a rubber band.

C. Lay the three thermometers on books, as shown in Figure 11 • 7. Read and record temperatures from each thermometer once per minute for five minutes.

Figure 11 • 7. Setup for Procedure C.



INTERPRETATIONS

1. Using the kinetic theory of heat, explain the results of this experiment.
2. What information does this experiment yield about the attraction between alcohol molecules as compared with the attraction between water molecules?
3. Suggest some practical applications of the effects observed in this investigation.

INVESTIGATION 11.5: Heat and Molecular Attraction

(pages 270–271)

To explain their observations, students should realize that temperature is a measure of the average kinetic energy of molecules in a sample and that fast moving molecules are the most likely to break away from the attraction of other molecules in a liquid. From these two ideas, they may logically conclude that attractions among molecules in alcohol is less than molecular attractions in water. Water retains more of the fast moving molecules and therefore has a higher temperature than alcohol.

PROCEDURES

A. No comment.
B. Caution students not to let alcohol drip on the furniture or floor; it may ruin the finish.
C. No comment.

INTERPRETATIONS

1. According to the kinetic theory, the speed of molecules in a substance may vary greatly from place to place and from molecule to molecule. It is the average kinetic energy of the molecules that determines the temperature of the substance. Alcohol molecules are in the liquid phase (and are thus close together) on the cloth surrounding the thermometer bulb. Some of the faster-moving molecules have sufficient energy to enable them to escape from the attractive forces of the other molecules in the liquid. They can therefore enter the gaseous, or vapor, phase. Since the faster-moving molecules are no longer present in the liquid, the average velocity of those which remain will be lower than the original average. With the lowered average velocity (and lowered average kinetic energy), we find a lower temperature.

   The same process occurs with the water molecules; the thermometer with the water-soaked cloth around the bulb showed a lower temperature than did the thermometer wrapped in dry cloth. Since the temperature of the alcohol fell more rapidly than did that of the water, the rate of evaporation (change from the liquid to the gaseous phase) must have been more rapid in the alcohol.
2. If the alcohol evaporates more rapidly than does water, the attraction between the molecules in the liquid alcohol must be less than the attraction between the water molecules.

3. The cooling effect of evaporation can be useful to us. A canvas water bag may be convenient to use in the desert. Some water seeps through to the outside of the bag and evaporates. This lowers the temperature of the remaining water. Evaporative coolers are used in homes or automobiles in dry parts of the country. Our bodies are cooled by the evaporation of perspiration.

INVESTIGATION 11.6: Heat Flow

Heat can be transferred from one substance to another. But what determines the direction of heat flow? You may find the answer in this investigation.

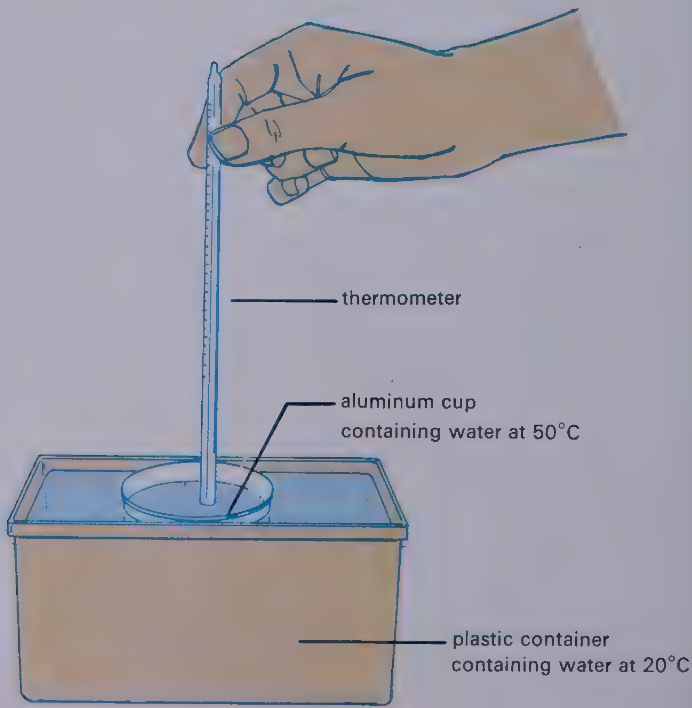
MATERIALS (per team)

- Plastic container (about 4 inches across and 5 inches deep)
- Aluminum cup (about 2½ inches in diameter and 5 inches deep)
- Supply of water at 20°, 50°, and 80°C
- Thermometer
- Graduated cylinder

PROCEDURES

A. Pour 200 ml of 20°C water into a plastic container, and 200 ml of 50°C water into an aluminum cup. Record the temperatures in your notebook.

Figure 11 • 8. Setup for Procedure B.



B. Put the aluminum cup inside the plastic container as shown in Figure 11 • 8. Take the temperature of the water in the aluminum cup every thirty seconds for five minutes. Record the time and the temperature for each observation. Empty the cup and the plastic container.

C. Repeat Procedures A and B, but pour 80°C water into the plastic container.

INTERPRETATIONS

1. In Investigation 11.3, you added hot water to cold water and observed the temperature change. What was the experimental purpose of introducing the aluminum cup as a barrier between the samples of water in the present experiment?
2. Does the aluminum cup influence the *direction* of heat flow?
3. How do you suppose the aluminum cup affected the rate of temperature change in the 50° water (as compared to simply mixing the samples of water)? That is, would the rate of temperature change have been faster or slower without the aluminum barrier between the samples?
4. Explain how the aluminum barrier affects the rate of temperature change. Use the kinetic theory of heat to develop your explanation.
5. How would the rate of temperature change be affected if a plastic cup were used instead of the aluminum cup?

INVESTIGATION 11.6: Heat Flow

(pages 272–273)

This investigation develops the concept that heat flows from regions of high temperature to regions of low temperature. Students should interpret this effect in terms of the behavior of molecules. In Investigations 11.2 and 11.3, students saw the effects of mixing hot water with cold water. They may have developed the idea that the final temperature of the mixture was simply the result of mixing "heat" and "cold." The aluminum barrier in the present investigation should help make the nature of heat flow more obvious to the students. Obviously the aluminum cup does not "care" which way the energy flows through it. Something about the temperatures of the water samples must determine the direction of heat flow. This is consistent with the view that temperature is a measure of the average molecular energy. If the molecules striking one side of the barrier have more energy on the average than the molecules striking the other side, the flow of energy through the barrier will not be the same in both directions.

MATERIALS

The aluminum cups can be made from aluminum beverage or soup cans. If you paint half of the cans white and half black, they can be used in Investigation 11.7. You may wish to distribute the cans so that some teams will have one black and one white can, some will have two black cans, and some will have two white cans. In this way the effect of color can be evaluated (and eliminated as a significant cause of difference). The plastic containers must be large enough to hold the aluminum cups and small enough to cause the water to rise about ⅔ of the way up the aluminum cup.

Time will be saved if supplies of water at (approximately) the three temperatures called for are available for the class.

PROCEDURES

A. It is not critical that the water temperatures be exact.
B. The temperature of water in the aluminum cup will decrease.
C. The temperature of water in the aluminum cup will increase.

INTERPRETATIONS

1. The aluminum cup prevents the water samples from mixing. Since aluminum is a good conductor of heat, it still allows the heat to flow.

2. The cup cannot influence the *direction* of heat flow. (The direction is determined by the temperatures of the substances on each side of the barrier.)
3. The aluminum cup slows down the rate of temperature equalization. Ask students to recall the effect of mixing hot and cold water in Investigations 11.2 and 11.3.
4. Without the aluminum barrier, high-energy water molecules (from the hotter sample) would collide directly with lower-energy molecules (from the cooler sample). This would distribute the energy more quickly than when the cup prevents the higher-energy molecules from mixing directly with the low-energy molecules. Stirring the hot and cold water together hastens the scattering of the faster-moving molecules throughout the liquid. Remember that according to the kinetic model, temperature is a measure of the average kinetic energy of the molecules. Mixing the liquids insures that the average speed of the molecules in any one region will not be greatly different from the average in any other region of the mixture. When the aluminum cup is present, only those molecules which hit the barrier have a good chance of losing energy. If the samples are mixed, each high-energy molecule has a good chance of colliding with a low-energy molecule and losing energy.
5. Since plastic is not a good conductor of heat, the rate would be much slower. (Some students may want to try this experimentally.)

INVESTIGATION 11.7: Color and Heat

You have gathered information about heat energy. You know heat energy can "flow" through solids and liquids. In molecular terms, heat energy flows through solids and liquids by means of collisions of atoms (or molecules) with other atoms.

There is another way in which heat energy can be transferred, and Investigation 11.7 provides an opportunity for you to observe it.

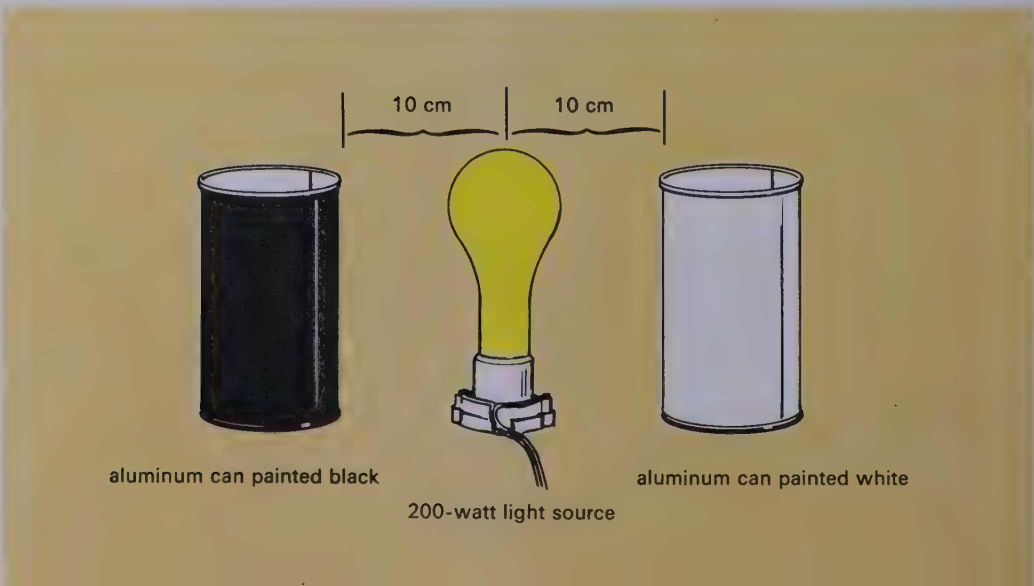
MATERIALS (per team)

Aluminum cans, 2, same shape and size, one painted dull black, the other white (about 250 ml)
Thermometers, 2
Light source (uncovered 150–200 watt bulb)
Graduated cylinder
Ruler

PROCEDURES

A. Pour 100 ml of water into each can.
B. Place a thermometer in each can and record the temperatures.
C. Place the cans 10 cm from the *center* of the light bulb, on opposite sides of the bulb (Figure 11 • 9).

Figure 11 • 9. Setup for Procedure C.



D. Divide your team into two groups. Each group is responsible for reading and recording temperatures in one of the cans. Readings should be made at the same times by the two groups. Turn on the light and record the temperature of the water in each can every three minutes. Continue the readings until there is no change in temperatures for three consecutive readings or until thirty minutes have elapsed.

INTERPRETATIONS

1. How do the final temperatures in the two cans compare?
2. What does the *rate* of temperature change in each can indicate about the rate at which heat flowed into the water?
3. Did heat leave the water? How could you tell?
4. From the position of each can in relation to the heat source, what can you say about the rate at which heat was reaching the cans?
5. Can you use the kinetic theory of heat to explain the results of this experiment?

PROBLEM

Explain why many people who live in hot, sunny parts of the country prefer white or other light-colored clothing instead of dark clothing.

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INVESTIGATION 11.7: Color and Heat

(pages 274–275)

Many people do not realize that there is a relationship between color and heat. Yet this relationship is important for students to understand. It can make life more comfortable for them at certain times of the year. Students should observe that heat can be transferred by radiation. They should also learn that a black object is more efficient than a white one in radiating and absorbing heat energy.

PROCEDURES

A.–C. No comment.

D. The temperature of the water in the black can will rise more rapidly than the temperature in the white can.

INTERPRETATIONS

1. The water in the black can should be hotter than the water in the white can.
2. Heat flowed into the water in the black can more rapidly than into the water in the white can.
3. Since the temperature of the water in the cans is higher than room temperature, it is reasonable to assume that heat is passing from the cans into the surrounding air. This can be easily observed if students fill the cans with fairly hot water and then measure temperatures at different times without the light source. If you have extra cans, you might have the students measure the relative rates of heat loss from white and black cans.
4. Because each can was the same distance from the heat source, it is reasonable to assume that heat reached each can at the same rate.
5. The kinetic theory of heat as developed to this point will not adequately explain the transmission of heat from the lamp to the cans. Heat from the sun comes to us across millions of miles of space. In this space there are very few molecules to interact and pass this energy from one to another. Some discussion of the *radiation* of heat will be presented in the last part of Section Thirteen.

The results of this experiment indicate that the molecules of black paint must absorb heat energy and transmit it to the can more rapidly than do molecules of white paint, all other factors being equal.

PROBLEM

White paint reflects much of the heat radiated from the sun, while black paint absorbs a great deal of it. For this reason, the inside of a

white automobile is cooler than the inside of a black one, when both are exposed to the sun's rays. Similarly, white clothing is cooler than black clothing of the same material and thickness when worn in the sunlight.

SUPPLEMENTARY MATERIALS

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FILMS

Heat and Its Control. Bureau of Mines Film #192. 20 minutes. Black and white. The film extends the text coverage of heat. It should be shown after completion of the section. Available on free loan from Bureau of Mines, 4800 Forbes Ave., Pittsburgh, Pa. 15213.

Kinetic Molecular Theory. McGraw-Hill Book Co. 9 minutes. Color.

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FILM LOOP

An Inquiry into Heat. Inquiry in Physical Science, Interaction Film Loops. Chicago: Rand McNally & Co., 1972.

SUGGESTED ACTIVITIES FOR TESTING LABORATORY SKILLS AND TECHNIQUES

INVESTIGATION 11.2

Measure a weight of water equal to the weight of a piece of metal. Compute the number of calories needed to change the temperature from one value to another for a specified weight of water.

INVESTIGATION 11.3

Predict the final temperature of a mixture of a given amount of ice with water of a known weight and initial temperature.

INVESTIGATION 11.4

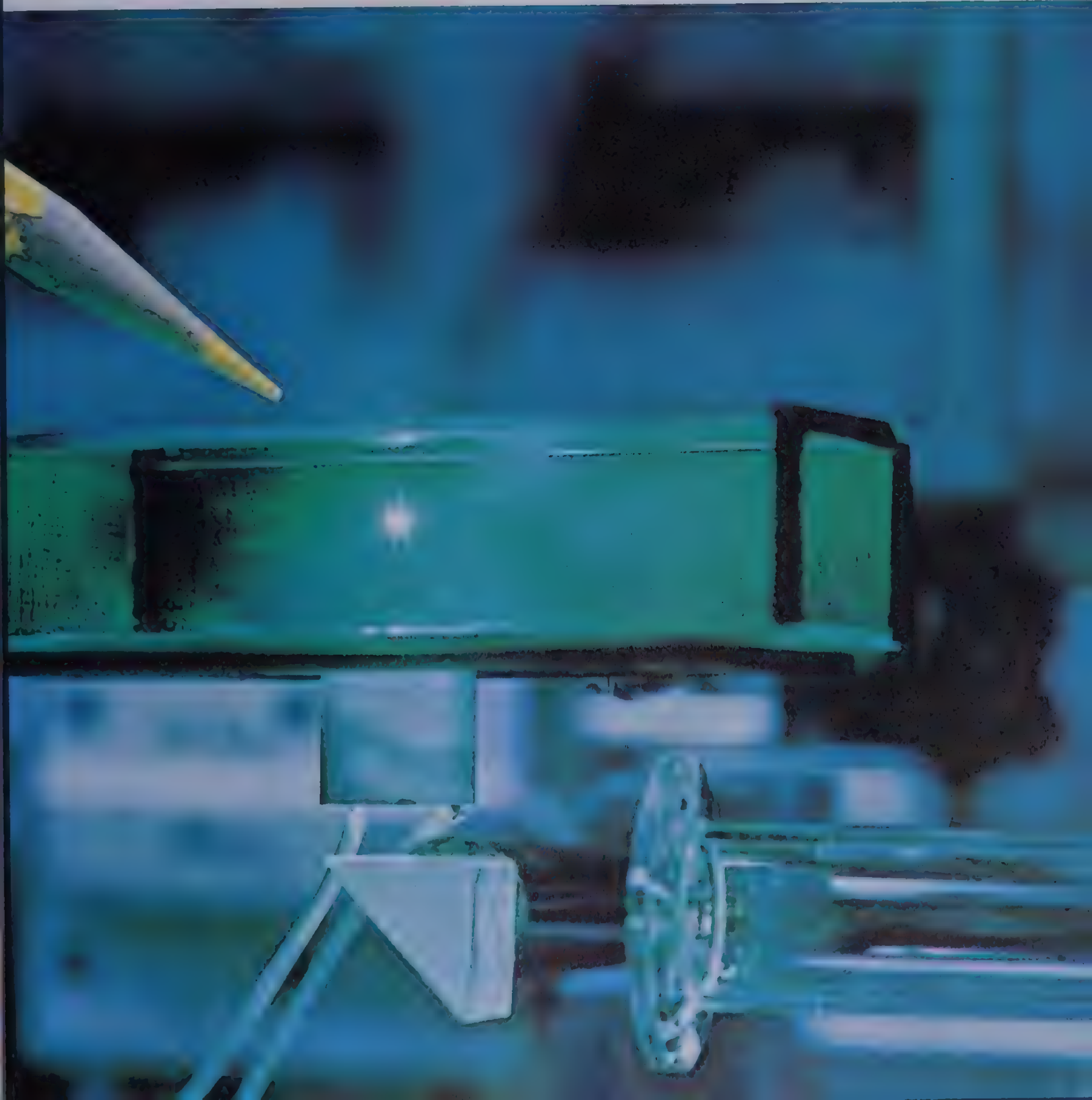
Control the movement of a drop of water in glass tubing.

INVESTIGATION 11.5

Wrap and fasten a moistened cloth around the bulb of a thermometer.

SECTION TWELVE

Observing the Behavior of Light



SECTION TWELVE

Observing the Behavior of Light

(pages 277–304)

Preview

Most investigations in Section Twelve will indicate that light appears to "travel" in a straight line.

Particle theories will be used to explain the pathway of light, but students will find that a particle theory cannot be used to explain the results of later experiments in this section. The possibility that light energy travels in waves similar to water waves will be introduced. Thus students will be faced with two different models—both of which are useful in interpreting the behavior of light.

The use of two models to explain one kind of event was once confusing for physicists—and it may be equally confusing for students. Since men began to investigate their surroundings in a scientific way, they have had to revise their models or, when necessary, create new ones. Light is such a complex phenomenon that particle and wave models are used to explain different facets of its behavior.

A model is something we impose on nature. It may be useful, but it can never be "true" or "false." A model can only be consistent with our observations. If new observations make it inconsistent, it must be revised. This was the fate of the demon hypothesis; it served a purpose, but it gradually became more cumbersome than useful. (It would be best to draw such judgments of the usefulness of the demon hypothesis from the students.) By now students should have created a more useful and simple model to explain the behavior they observe—an atomic model. If students fail to grasp the role of a model in science, they will have missed one of the concepts that makes science a truly creative activity.

The first investigation appears to show that light travels in a straight line. It is an easy investigation to set up, and most students will probably find it fascinating, but difficult to explain. The authors urge that students carry out Investigation 12.1. We also recommend that you

perform the investigation before asking students to do it. This, of course, should be done for all investigations if they are unfamiliar.

Investigation 12.2 introduces students to some properties of a mirror. It is an intriguing investigation and should be a challenge to everyone in the class. If you have enough pocket mirrors available, you may wish to have every student perform Procedure E, page 282.

Investigations 12.3 to 12.5 also deal with various mirror reflections, but are slightly more difficult. You may wish to assign these investigations to different students on an individualized study basis. Following Investigation 12.5, there is an "On Your Own" investigation with mirrors. It should prove challenging to most students.

During Investigation 12.6, students will observe how light is refracted in various ways as it passes from one substance through another substance. This leads them to consider another model for the behavior of light

The behavior of water waves in a homemade ripple tank is then compared to light traveling in the form of waves. Later, students study interference patterns and light diffraction. They then compare interference patterns and diffraction of light with similar phenomena that they have previously observed in water waves.

The photograph opening Section Twelve shows a small glass bead supported by a laser beam. The beam, which is barely visible, leaves the laser tube at the lower right, is bent by the prism, and enters a vacuum box. The tiny glass bead floats on the beam. The experiment was done at Bell Laboratories. Though lasers are not dealt with in IME, they make an excellent individual project for advanced students.

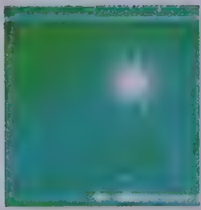
PLANNING AHEAD

Please read through the section to make sure you have the material on hand for each investigation.

LEARNING OBJECTIVES

Given the opportunity to inquire, to investigate, to interpret data, and to offer hypotheses about the activities in this section, most students should be able to—

- Observe and describe the nature and behavior of light energy;
- Offer hypotheses to explain the various behaviors of light;
- Propose particulate models for light behavior;
- Design investigations of multiple reflections;
- Propose wave models for light behavior;
- Analyze and reevaluate the two different models needed to account for the complex behavior of light.



Light, like heat, is a familiar form of energy. Light energy behaves in many different ways. A magnifying glass can focus energy from the sun into a beam that produces enough heat energy to set a piece of paper on fire. Thus light energy and heat energy are apparently related.

Sunlight travels a distance of 93 million miles at a speed of 186,000 miles per second before it strikes the earth. Without sunlight, life could not exist on this planet. Light also affects the behavior of most plants and animals, including man. Most of us, for example, regulate our activity by the sun, working during daylight hours and sleeping during the night. Many kinds of insects are attracted toward light. If you leave a door or window open in your house on a warm summer night, you know that many small insects soon will be flying around the lamps inside. Some insects and other animals move away from light. Early man discovered that the light from his fire would keep wild animals away at night.

A study of the relationships between light and life would require much more time than we have in this course.

During the following investigations of light, you will again be asked to construct a model—a model on which to base your understanding of light energy. As you construct the model, consider the following questions: Is sunlight the same kind of light as that given off by a glowing light bulb? How does light travel? What is the relationship between light and color? What causes a rainbow?

Do not attempt to answer these questions now. But keep them in mind as you investigate the phenomenon of light. Perhaps your study will yield some answers to the questions. Keep in mind that scientists do not completely understand the nature of light. But they continue to study its behavior and to build models that may someday reveal more about light energy than is now known.

INVESTIGATION 12.1: Observing a Light Beam

By observing a beam of light, you may get some idea about the way it travels.

MATERIALS (per team)

Shoe box
A nail or other pointed object
Knife or razor blade
Tape
Light source (penlight or conductivity-meter light)
Mirror

PROCEDURES

A. Using a nail, punch a hole about ⅛ inch in diameter in the center of each end of a shoe box and in the center of the box top (see Figure 12 • 1). Punch the holes from the inside out. Trim off any ragged material around the holes with a sharp knife or razor blade. Put the lid on the box and fasten it with a few pieces of tape.

B. Have one member of your team hold the light against the hole in one end of the box. Look into the box through the hole in the opposite end. Then look through the hole in the top of the box. Have each member of your team make these observations.

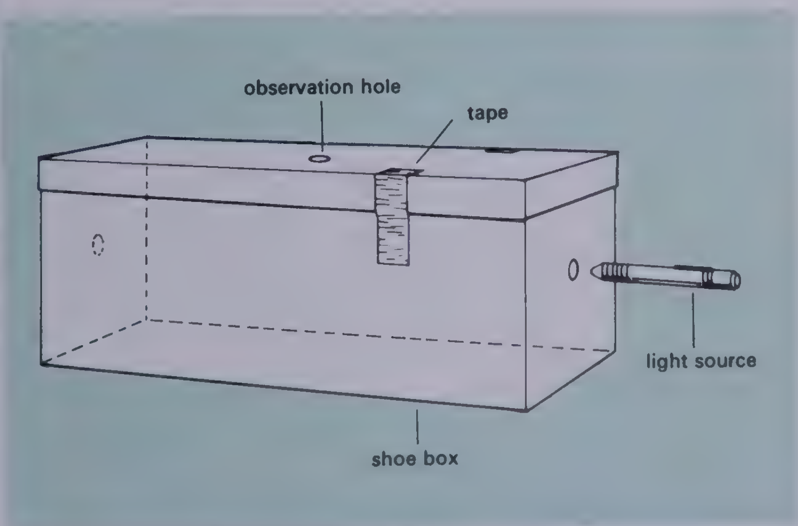


Figure 12 • 1. Setup for Procedures A and B.

INTERPRETATIONS

1. Describe and explain any difference in what you saw when looking through the two holes.
2. What appears to be the pathway of light? Verify your answer by shining a flashlight on the wall.
3. Can a light beam be bent so that it will travel around corners?

PROCEDURES

C. Shine a flashlight beam on a mirror. Hold the mirror at an angle so light striking the mirror will be reflected toward a wall or other solid surface.

INTERPRETATIONS

4. In what way is the reflection of light from a mirror similar to a ball bouncing against a wall? In what way are these two events not similar? From the results of this investigation, suggest a model that could explain the nature of a light beam.

INVESTIGATION 12.1: Observing a Light Beam

(pages 278–280)

Through a simple activity, students gain evidence that light seems to travel in a straight line. It is likely that one class period will be enough time to complete both this investigation and the next one.

MATERIALS

Shoe boxes are suggested because they are well constructed and are usually easy to obtain. Any box of similar size would be suitable. You may prefer to prepare the boxes in advance and eliminate Procedure A. The box should be taped to eliminate extraneous light.

PROCEDURES

A. Each of the holes should be about ⅛ inch in diameter.

B. Make sure that students view the light through the hole opposite the light source *before* looking into the box from the top.

INTERPRETATIONS

1. From the opposite end of the box the light source is plainly visible. When students look through the hole in the top, they will see no light at all. If chalk dust is introduced into the box, the beam will be visible from the top.

   Students are often astonished by this experiment. Many ask, "Where did the light go?" The reason the box appears dark when viewed from the top is that a *beam* of light is not visible unless dust or some other material causes the light to scatter or unless the beam strikes the viewer's eye.
2. This experiment supports the hypothesis that light travels in a straight path. A flashlight beam directed onto a wall illustrates the same hypothesis.
3. The question may elicit several answers. Accept each suggestion as a possibility, but avoid giving answers at this time. Later investigations will show that light can be "bent" under certain conditions.

PROCEDURES

C. This procedure may be easier to perform in a darkened room.

INTERPRETATIONS

4. The reflection of a light beam and the bouncing of a ball are similar in that the ball can be thought of as a light beam and the side of a

building as a mirror. A ball thrown against a wall does not bounce back in a straight path, even if it is thrown hard without any arc. As soon as the ball leaves the point of impact, gravity causes it to fall toward the earth. Apparently gravity has little effect on light; a light beam does not exhibit any dip after being reflected by a mirror, no matter what the direction.

Guide students toward the concept that light consists of very small particles of energy. The particles would have to be so small and moving at such a great speed that gravity would have no visible effect on them. (This model may also provide the basis for a study of quantum theory for those students who go on to study physics in depth. We do not think the term *quantum* should be introduced here, and the theory is beyond the scope of this course.) If light is composed of energy particles, it should travel in a straight path away from its source.

NOTE: *If, in previous science classes, your students have already investigated ray tracing using mirrors, you may want to assign Investigations 12.2 through 12.5 for home activity. However, even if students have done any ray tracing exercises with mirrors, many will have forgotten how to do these exercises and what they mean. Some interesting alternative activities with light are suggested on pages 483–492 of* A Sourcebook for the Physical Sciences, *by Joseph, Brandwein, Morholt, Pollack, and Castka, 1961, Harcourt, Brace and World.*

INVESTIGATION 12.2: Some Properties of a Mirror

Mirrors are used to study the behavior of light in this investigation and several that follow.

MATERIALS (per class)

- Large sheet of white paper
- Wall mirror (at least 12 inches square)
- Masking tape
- Several sheets of tracing paper

MATERIALS (per team)

- Sheet of white paper
- Pocket-size mirror

PROCEDURES

NOTE: *Procedures A through D should be performed by two students as a demonstration for the class.*

A. Student 1 holds a large sheet of white paper against the chalkboard or a smooth wall. Student 2 stands facing away from the wall, with the back of his head against the paper. Using a pencil, Student 1 draws an outline of Student 2's head on the paper.

B. Student 2 stands 4 feet from the large mirror, facing it. Student 1 stands to one side of the mirror and places four small pieces of masking tape on the mirror, outlining Student 2's head *as Student 2 sees it*. Student 1 (following Student 2's instructions) places one piece of masking tape just even with the top of the reflection of Student 2's head, another at the chin, and the others at the ears.

C. Student 1 places a sheet of tracing paper over the tapes on the mirror and draws an outline of the head, using the four pieces of tape as reference points.

D. Compare the two outlines of Student 2's head. Record your observations.

INTERPRETATIONS

1. Which is larger—the outline of the head or the outline of the image?
2. What does this mean for anyone who looks into a mirror?

PROCEDURES

NOTE: *Procedure E is to be performed by each team.*

E. Write *TOM* on a sheet of paper. Hold a small mirror so that the letters can be seen as a reflection.

INTERPRETATIONS

3. Describe the reflected image.
4. Explain what you observed. If an explanation is difficult at this time, it will be less so after you have performed the next series of investigations.

Figure 12 • 2. Carrying out Procedure E.

INVESTIGATION 12.2: Some Properties of a Mirror

(pages 281–282)

Students should observe that mirror images are smaller than the actual object and exhibit an apparent interchange of left and right sides. These results are likely to puzzle some students. It is hoped that their desire to understand what they observe in this investigation will stimulate their interest in subsequent investigations on the behavior of light.

MATERIALS

If there is not a large mirror in the room, perhaps one can be borrowed from the home economics or health department. It is sometimes possible to use glass in a window in place of the large mirror.

PROCEDURES

A. If time allows, have several pairs of students perform Procedures A through D.

B. Student 1 must place the pieces of masking tape just where Student 2 directs.

C.–D. No comment.

INTERPRETATIONS

1. The outline of the reflected image should be much smaller than the other outline.
2. Many students will be surprised to learn that when you look into a mirror, you always see an image smaller than life-size.

When a person looks at a reflection of his head, the area of the mirror that reflects light into his eye is smaller than his head. The students will investigate the location of an image for a plane mirror in Investigation 12.4. After that investigation ask the students to trace the reflected light from an object to a point (such as an eye) and show that the area on the mirror is smaller than the object itself.

PROCEDURES

E. As a challenge for students of high ability, have them write the word *CHOICE* on a piece of paper. Have them hold it in front of a mirror as they did with the word *TOM*. Next ask the students to turn the paper upside down and again observe the mirror reflection. It will read the same—*CHOICE*. If repeated with *TOM*, the results will be quite different.

INTERPRETATIONS

3. The image will read *MOT*.
4. Avoid giving an explanation at this time. After the next series of investigations students should be able to explain why the mirror image is reversed.

Figure 12 • 3. Correct position of the mirror on the mirror line.

INVESTIGATION 12.3: Mirror Reflections

You have already observed some of the effects mirrors have on light. This investigation should help you to analyze these effects.

MATERIALS (per student)

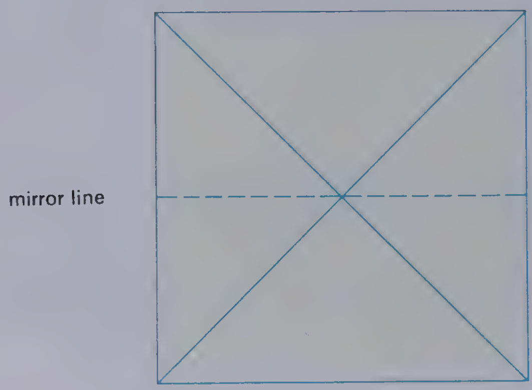
- Pocket mirror
- Ruler
- Unruled paper

PROCEDURES

NOTE: *In each of the following procedures, place the edge of the mirror along the mirror line (dotted line), as shown in Figure 12 • 3. Always hold the mirror perpendicular to the surface, as shown.*

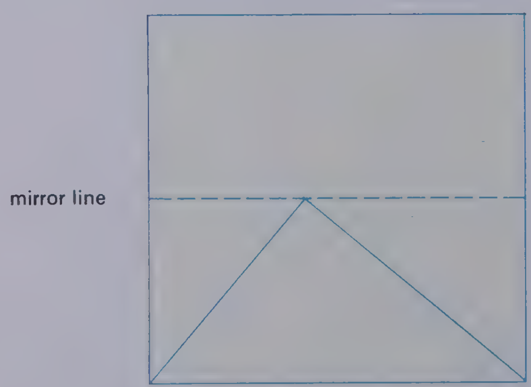
A. Hold the mirror on the mirror line in Figure 12 • 4. Where does the diagonal line that extends from the lower *left-hand corner* of the square appear to be in the reflection? Record your answer. Answer the same question for the diagonal line that extends from the lower *right-hand* corner.

Figure 12 • 4.



B. Hold the mirror on the mirror line in Figure 12 • 5. Where do the diagonal lines that extend from the corners of the square appear to be in the reflection? Record your answers.

Figure 12 • 5.



C. In your notebook, draw a copy of Figure 12 • 6. Draw a line in the upper half of the square where you think the image of the line on the lower half of the square would appear.

D. Hold the mirror on the mirror line in Figure 12 • 6. Where does the image of the diagonal line appear to be in the reflection? Record your observation.

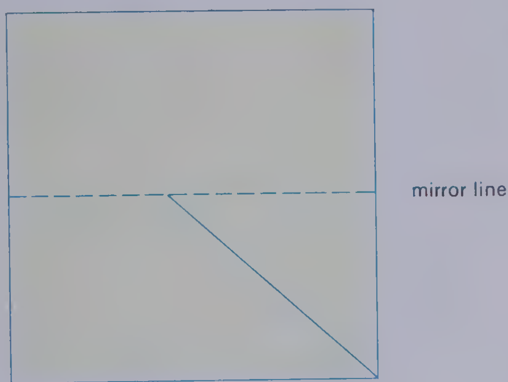


Figure 12 • 6.

INTERPRETATIONS

1. Did your drawing in Procedure C match the mirror image of the diagonal line in Figure 12 • 6?
2. How are lines reflected in a mirror? Assuming that light is made up of small particles, how would you explain your answer?

INVESTIGATION 12.3: Mirror Reflections

(pages 283–285)

These activities should lead the student to believe that light reflected from a mirror *appears* to come from behind the mirror.

MATERIALS

Each student should have a pocket-sized mirror.

PROCEDURES

A.–C. Students should be advised to follow the instructions *exactly* as written. They should *not* have pencils or pens in their hands while carrying out Procedures A and B, except when they are recording observations.

D. Students' drawings will vary.

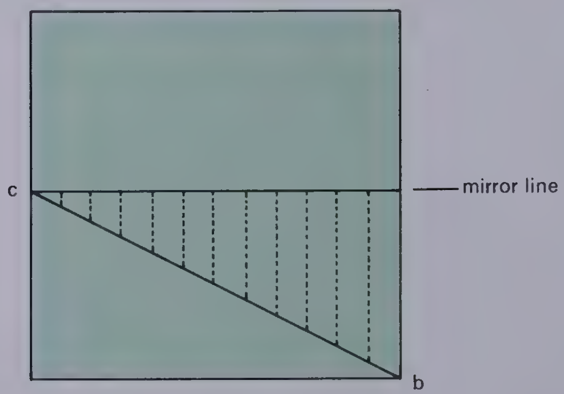
INTERPRETATIONS

1. Some students will have drawn the line just as it appears in a mirror; others will not.
2. This may prove difficult. If students are unable to apply their particle model of light to this interpretation, you may wish to have them perform the following exercise:

PRACTICE EXERCISE

Draw Figure T-12 • 1 on the chalkboard. Explain that each vertical dotted line represents a particle of light being reflected from Line CB. Then ask them to carry out the following procedures.

Figure T-12 • 1.



PROCEDURES

A. Copy the diagram on a sheet of white paper.

B. Place your mirror on Line CB. Slowly move the right end of the mirror to the mirror line—but no farther. Move the mirror counterclockwise, pivoting the left end of the mirror on Point C.

INTERPRETATION

Which "light particles" must travel the greater distance—those near *C* or those near *B*?

We hope that students will be able to relate this experience to their particle model of light. The dotted lines appear to lengthen. Students should suggest that the farther light must travel from Line CB before striking the mirror, the farther will that part of the line from which the light came appear to be "behind" the mirror.

INVESTIGATION 12.4: An Image "Behind" a Mirror

When you look at a reflection in a mirror, moving your head will make the reflection move. Does the image you see really move, or does it appear to move only because of your motion? Careful observation in this investigation may help you find the answer.

MATERIALS (per team)

- Unruled paper
- Corrugated cardboard (8 x 8 inches)
- Tape
- Several straight pins
- Pocket mirror
- Mirror support

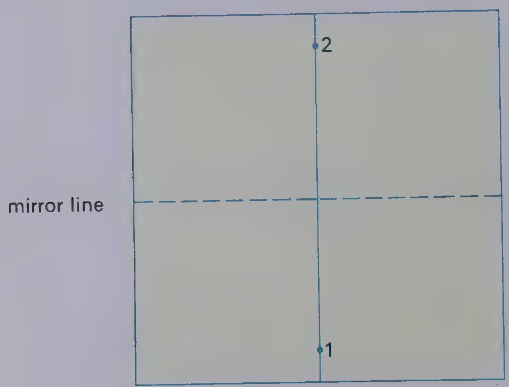


Figure 12 • 7.

PROCEDURES

A. On a sheet of white paper, draw an enlarged copy of Figure 12 • 7. The square should be 4 inches on a side. Note that Points 1 and 2 are equal distances from the edge of the square. Tape the sheet of paper to the cardboard.

B. Insert one pin at Point 1 and a second at Point 2. Set the pins firmly so they stand perpendicularly to the paper.

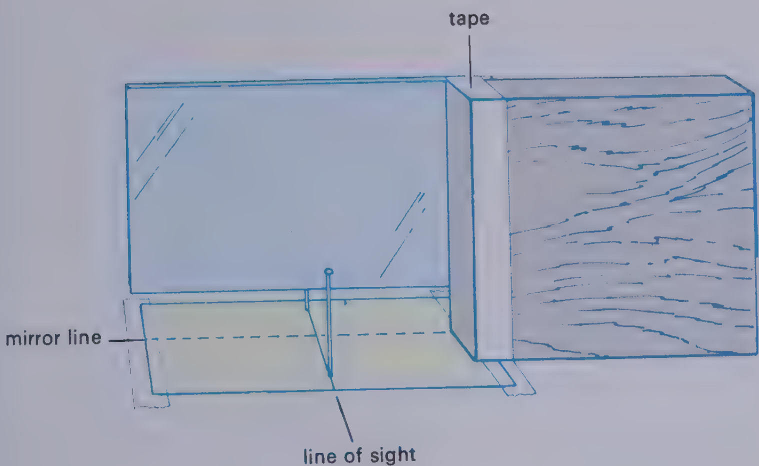


Figure 12 • 8. Setup for Procedures C and D.

C. Support the mirror so its bottom edge is 2 cm above the paper (see Figure 12 • 8). By looking under the mirror, you can see the lower part of Pin 2 behind the mirror.

D. Look under the mirror. Do you see any relationship between the mirror image of Pin 1 and the bottom of Pin 2? View the two pins from the left and from the right.

E. Place Pin 2 at other locations behind the mirror. Observe the relationship of the mirror image of Pin 1 to the bottom of Pin 2.

INTERPRETATIONS

1. Describe what you observed in Procedure D.
2. Did you observe the same effect when the position of Pin 2 was changed?
3. How do these observations compare with the results obtained in Investigations 12.2 and 12.3? Compare the distance that an image of an object appears to be "behind" a mirror with the actual distance from the object to the mirror.

INVESTIGATION 12.4: An Image "Behind" a Mirror

(pages 286–287)

Students gather enough evidence to become convinced that the image is always as far "behind" the mirror as the object is in front of it.

MATERIALS

It is critical that the mirror support be heavy enough to support the mirror just above the mirror line. Tape the mirror onto the side of the support.

PROCEDURES

A. The figure must be a nearly perfect square, with the mirror line equidistant from the top and bottom edges of the square. To save time you might prepare a Ditto master and make a copy for each student.

B. It is critical that the pins be placed in a perpendicular position and at equal distances from the mirror line.

C.–E. No comment.

INTERPRETATIONS

1. The image of Pin 1 should appear to form the top of Pin 2 regardless of the position from which the two pins are viewed.
2. When Pin 2 is placed in any other position, the image of Pin 1 will no longer appear to coincide with Pin 2, no matter what the viewing positions are.
3. The distance that an image appears to be "behind" a plane mirror is always equal to the distance from the object to the mirror. If a person views himself in a mirror from a distance of 4 feet, his image will appear to be 4 feet "behind" the mirror.

INVESTIGATION 12.5: Comparing Angles When Light Is Reflected

How does the angle at which light strikes a mirror compare with the angle at which the same light is reflected? Finding an answer to this question may help you to understand why mirror images behave as they do.

MATERIALS (per team)

- Unruled paper
- Ruler
- Corrugated cardboard (8 x 8 inches)
- Tape
- Pins, 4
- Pocket mirror
- Mirror support
- Protractor

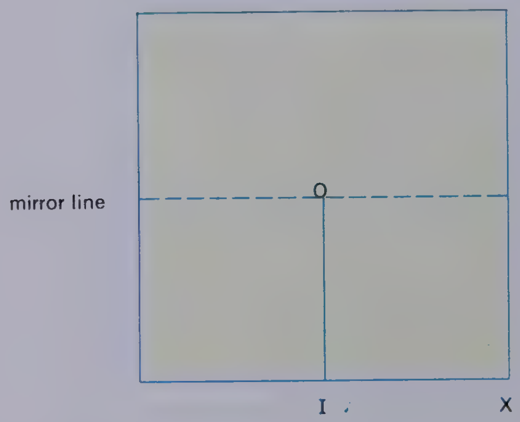


Figure 12 • 9.

PROCEDURES

A. On a sheet of white paper, draw an enlarged copy of Figure 12 • 9. The square should be 4 inches on a side. Tape the paper to the cardboard.

B. Draw a line connecting Points X and O. Insert two pins about 1 inch apart on Line XO.

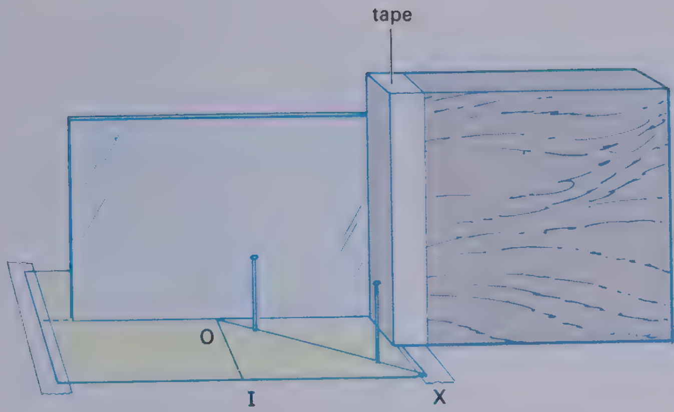


Figure 12 • 10. Setup for Procedures C–F.

C. Using the support, place the mirror on the mirror line (see Figure 12 • 10).

D. Look into the mirror from the left. Move sideways until the images of the two pins line up exactly, one behind the other. Place two more pins on the left side of the paper so that they line up exactly with the images of the first two pins. Remove the mirror. Draw a straight line from the mirror line, through the two new pin points, to the edge of the square.

E. Using a protractor, measure and record (in degrees), first, the angle formed by Lines XO and OI, and second, the angle formed by Line OI and the line that you added at the end of Procedure D.

INTERPRETATIONS

1. How do the two angles compare?

PROCEDURES

F. Remove the pins on Line XO. Draw a line from some other point on Line IX to Point O. Place two pins on this line about 2 inches apart. Set the mirror on the mirror line and repeat Procedures D and E. Repeat, using several other lines; each time, measure the two angles formed by the two sets of pins and Line OI.

INTERPRETATIONS

2. What general statement can you make about the relationship between the angle at which light strikes a mirror and the angle at which light is reflected?
3. Does the behavior of light in this investigation support the particle model of light? Upon what evidence do you base your answer?

ON YOUR OWN: More about Mirror Reflection

This investigation may be performed after school or at home. Or, your teacher may decide to have you perform it during class hours.

Several ideas for using mirrors are given to you. But you may be able to devise many other experiments with mirror reflections. An explanation of your results should be compared with those of Investigation 12.5.

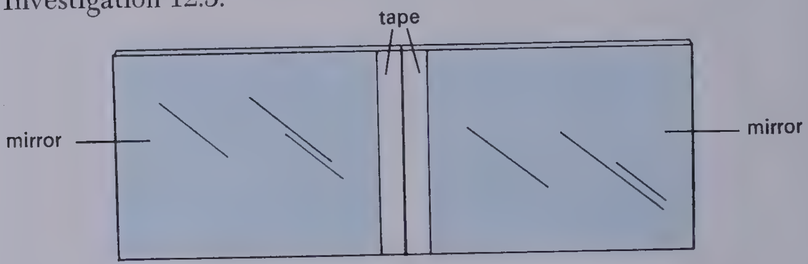


Figure 12 • 11. Two pocket-size mirrors, reflecting side up.

If rectangular mirrors (pocket size, approximately 6 x 7½ cm) are used, prepare two mirrors as follows: place them, reflecting side up, end to end on a flat surface; fasten them together with a narrow strip of transparent tape (Figure 12 • 11). The tape will act as a hinge and also make it easier to handle the mirrors.

Next, move the mirrors so that one lies flat and the other stands perpendicularly to the flat mirror. Support the mirrors by placing the back of the vertical mirror against a book or other fairly heavy object (Figure 12 • 12). Now cut out a strip of newspaper about 4 cm wide and 12 cm long. The type *must* run lengthwise.

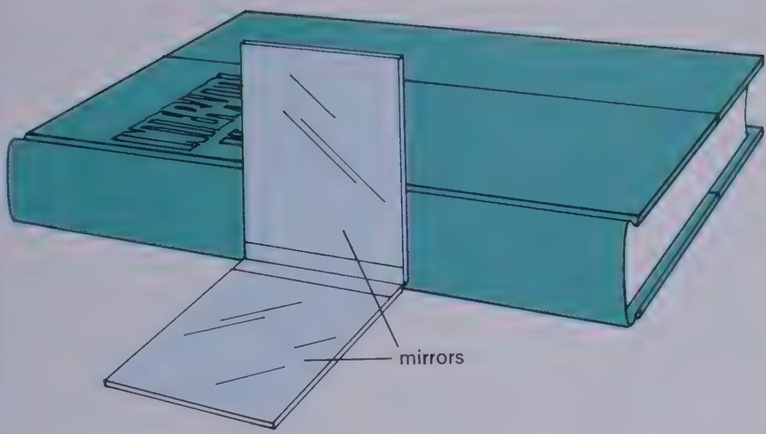


Figure 12 • 12. The vertical mirror, supported by the book, forms a 90° angle with the horizontal mirror.

Fold the strip lengthwise. Unfold it so that it forms approximately a 90° angle. Place it on the *flat* mirror with the type facing the vertical mirror. Adjust the paper strip so that you see two images, one on the vertical mirror and one on the flat mirror. Observe images from both sides of the mirrors. In your notebook, try to explain your observations in terms of what you learned in Investigation 12.5.

Remove the mirrors and place them on the table. The mirrors should be turned so that their long edges are parallel with the table. Straighten them out to form one long mirror, about 15 cm long and 6 cm high, with its reflecting side toward you. Place a pencil or pen flat on the table. Point it to the seam where the two mirrors join. The pencil should be at a right (90°) angle to the mirrors. You should see a reflection of the pencil. Leave the pencil in place and gradually fold the two mirrors in until they almost touch the sides of the pencil. Then record and explain your observations in your notebook.

If you have access to mirrors a third or more larger than your book, tape the mirrors together and place them on their sides. Hold your book open facing the two mirrors. Record and explain your observations as you did with the pocket mirrors.

Try other investigations with mirrors that illustrate what you have learned about how light travels.

INVESTIGATION 12.5: Comparing Angles When Light Is Reflected

(pages 288–290)

This investigation provides evidence that the angle at which light strikes a mirror is equal to the angle at which it is reflected.

PROCEDURES

A.–D. No comment.

E. Students may need help in using the protractor.

INTERPRETATIONS

1. The two angles should be very nearly equal, allowing for normal error. Many students may guess this before completing Procedure E. But they might not guess that the angles will be equal even when different lines are used, as in Procedure F.

PROCEDURES

F. No comment.

INTERPRETATIONS

2. The two angles are always equal. We have avoided using the terms *angle of incidence* and *angle of reflection,* but you may wish to include them.
3. Yes, this investigation reinforces the basis for a particle model that was first introduced in Investigation 12.1. Light reflected from the pins appears to travel in straight lines, and this is most easily explained with a particle model.

ON YOUR OWN: More about Mirror Reflection

(pages 290–291)

If there is difficulty in locating enough mirrors, each student or group of students might take turns. No one should disclose his or her results until everyone has had a chance to perform the two investigations.

Light reflected by mirrors at right angles will exhibit two reflections—in this case, of written or typed material. The second reflection reverses the image of the first reflection. Simply put, one sees a reflection of a reflection. If the directions are carefully observed, students

should see the typing or writing in its normal orientation on one side of the flat mirror, depending on which way they hold the printed material.

This could be done as a demonstration, but the opportunity for individualized study would be lost.

The second investigation with the pencil should be of interest to most students. As many as twelve pencil reflections have been observed when the two mirrors nearly touch the sides of the pencil. The explanation is similar to the preceding one. Each pencil reflection produces another reflection, and so on.

We cannot predict what innovations in mirror reflections students may try. They should be encouraged to investigate additional properties of a mirror if they show interest in the subject.

INVESTIGATION 12.6: Behavior of Light Passing through Different Substances

You have observed how light seems to travel through a transparent substance, air. Does light travel through other transparent substances in the same manner? What happens to a beam of light that goes from one transparent substance into another? Finding the answers to these questions is fundamental to building a model for light.

MATERIALS (per team)

Rectangular plastic box with cover
Wedge-shaped plastic box with cover
Tape
Unruled white paper
Pins
Corrugated cardboard (8 x 8 inches)
Ruler

PROCEDURES

A. Add water to both plastic containers until they are ¾ full. Put the covers in place and tape the edges securely to prevent leakage. Dry the outside of each container.
B. Tape a sheet of unruled white paper to the cardboard. Place the rectangular box in the middle of the paper. Draw an outline around the box. Remove the box and draw a dashed line from just inside the outline to the edge of the paper as shown in Figure 12 • 13.
C. Replace the box in the outline. Insert two pins on the dashed line on one side of the box.
D. Looking *through* the box from the side opposite the two pins, place two more pins on the near side so all four seem to be in a straight line. Remove the box and draw a solid straight line from the top edge of the paper, through the first pair of pins, to the edge of the outline. Draw a second straight line from

the bottom edge of the paper, through the second pair of pins, to the edge of the outline. Draw a third straight line connecting the points at which the two lines meet the outline.

INTERPRETATIONS

1. Are the four pins in a straight line?
2. Describe the pathway of light as it travels from air, through water, and into air. (Light reflected from the pins must follow this path when you look at them through the water.)

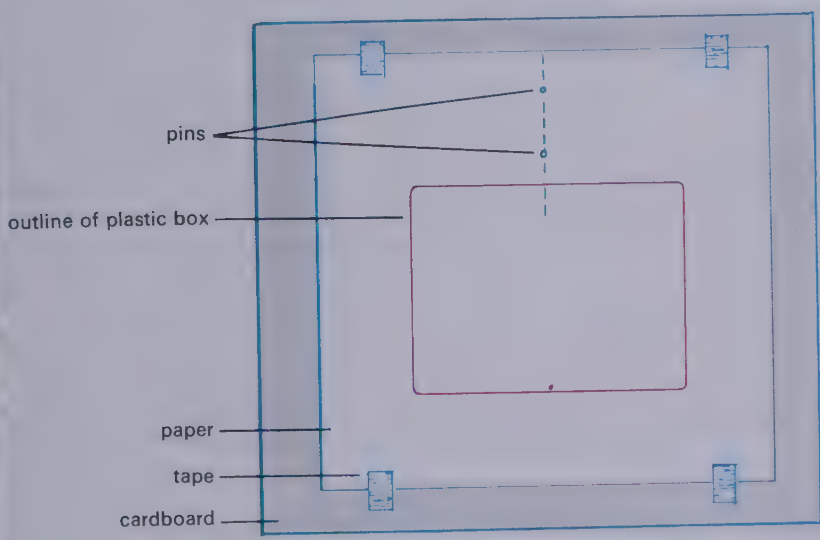


Figure 12 • 13. Setup for Procedures B–D.

PROCEDURES

E. Place the box in the outline again and insert the two pins as shown in Figure 12 • 14.

F. Look *through* the box from the side opposite the pins and place two more pins on the near side, so all four seem to be in a straight line. Remove the box and draw a solid straight line from the top edge of the paper, through the first pair of pins, to the edge of the outline. Draw a second straight line

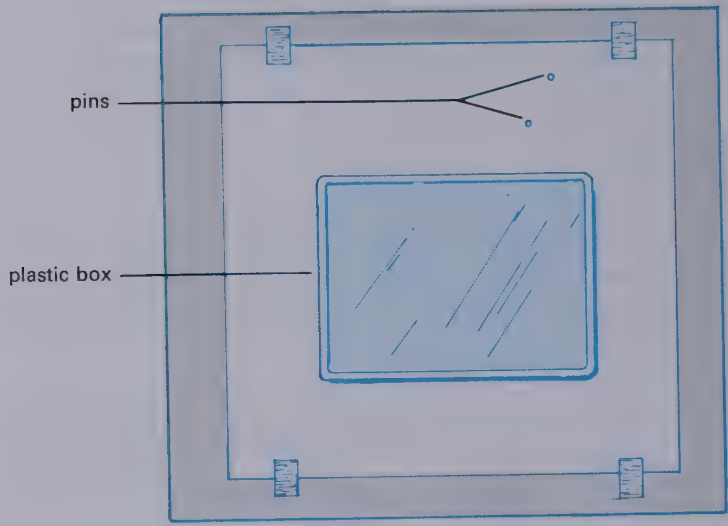


Figure 12 • 14. Setup for Procedures E and F.

from the bottom edge of the paper, through the second pair of pins, to the edge of the outline. Draw a third straight line connecting the points at which the two lines meet the outline.

INTERPRETATIONS

3. Compare the results of Procedures D and F.
4. Earlier you found evidence that light travels in a straight line. If this is so, how can you explain the results obtained in Procedure F?

PROCEDURES

G. Place the wedge-shaped box of water on a clean piece of white paper on the cardboard and draw an outline of its shape. Insert two pins as shown in Figure 12 • 15.

H. Look *through* the box from the side opposite the two pins. Place two more pins on the near side so all four seem to be in a straight line. Remove the box and draw a solid straight line from the top edge of the paper, through the first pair of pins, to the edge of the outline. Draw a second straight line from the bottom edge of the paper, through the second pair of pins, to the edge of the outline. Draw a third straight line connecting the points at which the two lines meet the outline.

INTERPRETATIONS

5. Describe the lines you drew in Procedure H. How do they compare with the lines drawn in Procedures D and F?
6. How can your model of light energy—from which we assume that light travels in straight lines—be made to agree with the results of Procedure H?

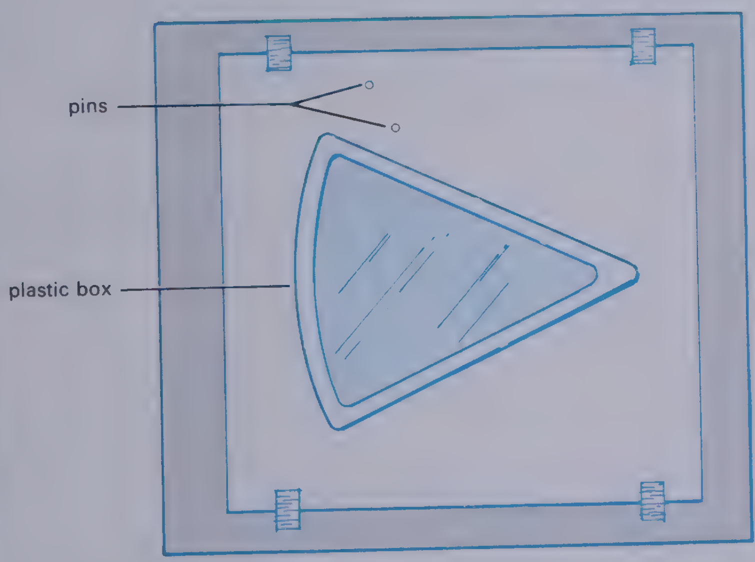


Figure 12 • 15. Setup for Procedures G and H.

INVESTIGATION 12.6: Behavior of Light Passing through Different Substances

(pages 292–295)

Students should observe that light may be bent as it goes from one transparent substance to another. A later investigation will show that waves are a suitable model for light since they behave in a similar manner.

MATERIALS (per team)

The plastic boxes are used to store food and are available in many variety stores. The boxes must be free from dirt or fingerprints.

PROCEDURES

A. To save time you may wish to fill the containers and seal them before class.

B.–D. No comment.

INTERPRETATIONS

1. The line should be straight.
2. Light appears to travel in a straight line.

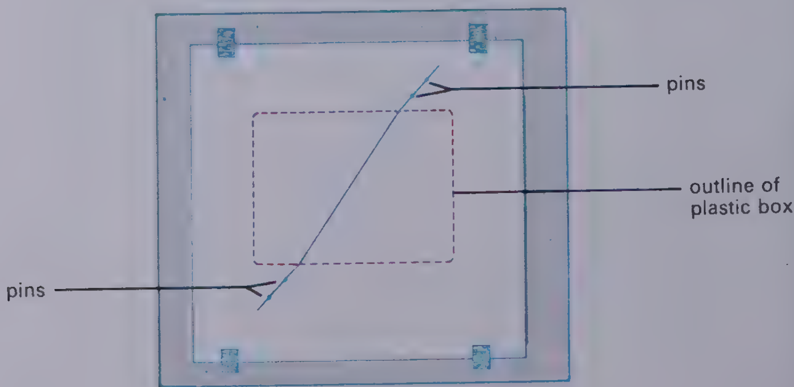
PROCEDURES

E.–F. No comment.

INTERPRETATIONS

3. The pins appear to be in a straight line when the student looks through the water. But when he attempts to connect the pins with lines, the result should be similar to Figure T-12 • 2. Light appears to bend as it passes from air, through water, and back into air.

Figure T-12 • 2.



4. At this point students probably will not be able to explain the bending of light. Welcome all opinions, but refrain from accepting any one explanation as correct.

PROCEDURES

G.–H. No comment.

INTERPRETATIONS

5. The lines will appear similar to those in Figure T-12 • 3.

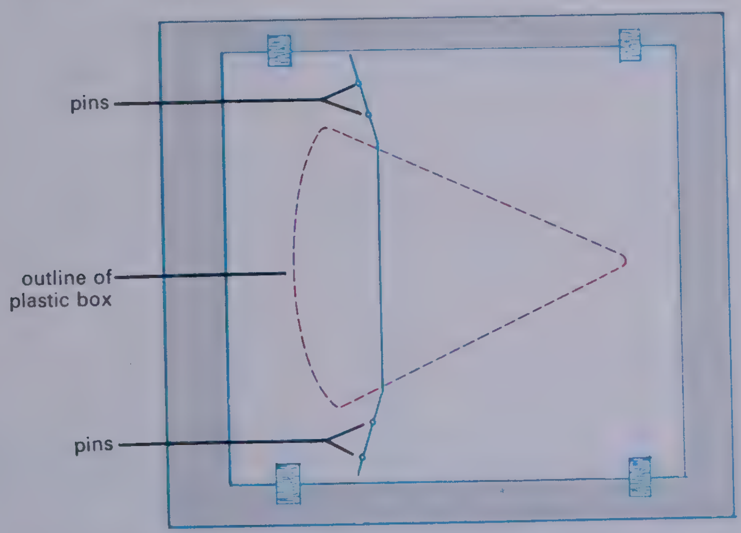


Figure T-12 • 3.

6. It cannot. Apparently light does not always travel in straight lines. If it did, the line connecting the four pins would be a straight line. The wedge-shaped box acted as a prism. When viewed through the wedge-shaped box, the pins appeared to line up. Since the pins can be seen only if light is reflected from them to our eyes, light passing through a wedge-shaped container of water must bend.

   It is possible to demonstrate the effect of a round "lens" on light by shining a flashlight through a small beaker or baby-food jar filled with water. The container acts as a lens, and the light is brought to a focus on the side opposite the light source. The point of focus can be moved by changing the distance between the light source and the container of water.

The next part of the section deals with a wave model of light. After seeing the ripple tank demonstration and performing additional investigations, students should use a wave model to explain how light can change direction when passing from one substance into another.

Another Look at a Model of Light

You know that moving particles possess energy. In many instances, the behavior of light can be explained with a particle model.

We can predict that when light strikes a smooth surface, such as the surface of a pond or a mirror, the light will bounce off (be reflected) and travel in a different direction. Almost every investigation of light you have performed makes a particle model of light seem reasonable. And the idea that light energy is composed of particles is often used by scientists to explain the behavior of light.

But how can we explain the bending of light when it passes from air into water and back into air? And why does light bend in different directions, depending upon the shape of the container

Figure 12 • 16. The force of waves pounding against a rocky shore is an example of natural energy at work.

and the angle at which light strikes the container? It is difficult to imagine how a particle could behave in this way. An alternative model of light will be investigated next. After completing all the investigations involving light, you should be able to refine your model so that every observation you make can be explained in terms of your model.

Observing the Nature of Waves

Huge ocean waves, created by winds or earthquakes, often cause great damage to coastal areas, destroying both property and lives. Tides and wave action gradually erode shorelines exposed to these forces.

It may be that wave action is a form of energy and that waves carry energy. Perhaps you live a great distance from an ocean or large lake and cannot observe the behavior of waves. But you can create ripples in a dish of water and investigate wave action on a small scale. The behavior of water waves may provide you with ideas for another model for the behavior of light.

In the following investigations, the behavior of waves in the ripple tank will be demonstrated. You are to observe each demonstration and record your observations. From your notes you will be asked to describe a general model of wave action that might explain the behavior of water waves and the behavior of light.

INVESTIGATION 12.7: Mirrors and Wave Action

In this investigation a piece of metal is used as a mirror to reflect water waves—just as an ordinary mirror reflects light.

MATERIALS (per class)

- Ripple tank with wave generator
- Overhead projector
- Pointed object (pencil)
- Metal "mirrors"

PROCEDURES

A. Observe the shape and motion of waves created when the water in the tank is disturbed with a pointed object. Record your observations.

B. A flat metal mirror has been placed in front of the ripple tank wave generator. When a pointed object disturbs the water, observe and record the appearance of waves as they are reflected from the mirror.

C. Unlike the pointed object, the wave generator creates waves along a broad front. Observe and record the appearance of these waves as they are reflected by the metal mirror.

INTERPRETATIONS

1. Compare the amount of wave motion present between the wave generator and the mirror with the wave motion present *behind* the mirror.

PROCEDURES

D. The metal mirror has been placed at an angle of about 45° in the ripple tank. Observe and record the direction of the *reflected* waves.

E. Now a curved mirror has been placed in the ripple tank. Observe and record the appearance of the reflected waves.

INTERPRETATIONS

2. Predict how light would behave when reflected from a curved mirror shaped like the one used in Procedure E.

Another Look at a Model of Light

(pages 296–297)

We believe students can understand the behavior of light more easily by moving from a particle model of light to a wave model than they could if the sequence were reversed. Eventually we hope students will accept *both* models of light as useful in interpreting the nature of light energy.

Students' understanding of both the wave model and the particle model should depend upon investigations and resulting interpretations, rather than upon lectures and reading assignments.

Observing the Nature of Waves

(page 297)

Wave action is a form of energy, and waves carry energy. The behavior of water waves provides students with ideas for another model to account for the behavior of light.

The behavior of waves in the ripple tank is demonstrated by the instructor. If enough equipment is available, teams of students may perform the investigation.

Students are asked to describe a general model of wave action that might account for the behavior of light.

INVESTIGATION 12.7: Mirrors and Wave Action

(pages 297–298)

In Investigations 12.7 through 12.9 most of the procedures are carried out by the instructor. The success of this series of investigations depends largely upon the teacher's skill in using a ripple tank. We urge that you practice each procedure before working in front of the class. An improvised ripple tank is shown in Figure T-12 • 4.

Before students begin this investigation, describe the operation of the ripple tank so they will be familiar with its use.

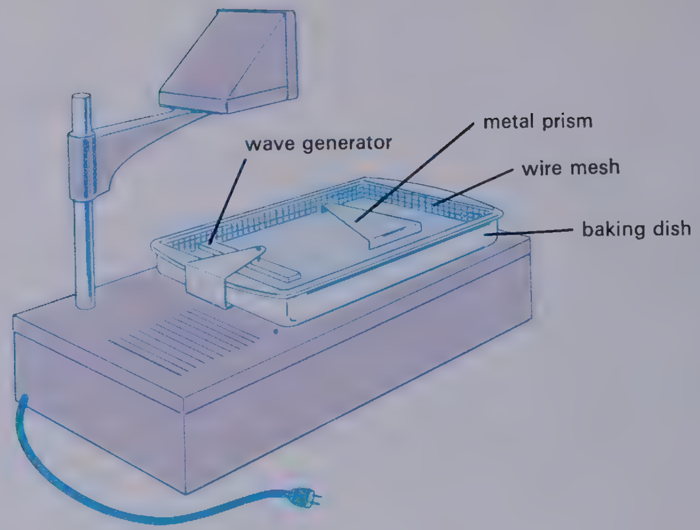


Figure T-12 • 4. Improvised ripple tank and overhead projector.

MATERIALS

A Sourcebook for the Physical Sciences, by Joseph, Brandwein, Morholt, Pollack, and Castka, 1961, Harcourt, Brace and World, has many helpful suggestions for making equipment. The construction of ripple tank apparatus is described on pages 460–462. Suggestions for the study of waves are found on pages 462–472.

PROCEDURES

A. Pour water into the ripple tank to a depth of about 1.5 cm. Repeatedly dip a pointed object (a pencil will do) into the water. The waves should appear as concentric circles expanding from the point of origin.

B. Place the metal mirror in the ripple tank so that it forms a barrier about halfway between the wave generator and the other end of the tank. Adjust the depth of the water so the mirror extends at

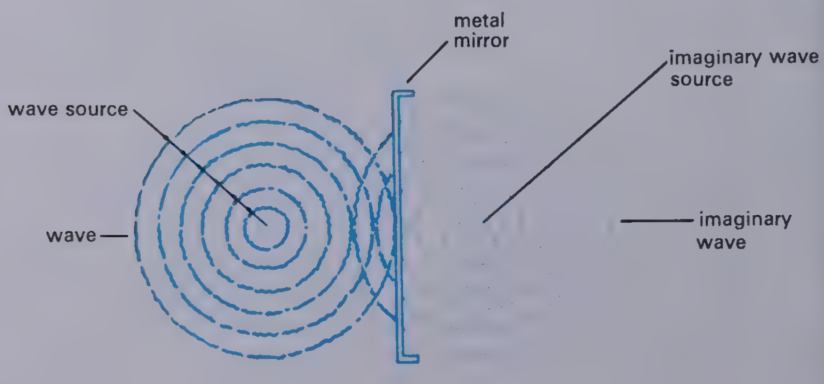


Figure T-12 • 5. Reflections of circular waves from a metal mirror.

least ½ cm above the surface of the water. Create concentric waves by repeatedly dipping the end of a pointed object into the water between the barrier and the generator. As the waves are reflected from the metal mirror, they will *appear* to come from a source *behind* the mirror, as shown in Figure T-12 • 5.

C. Activate the wave generator to create a series of broad waves moving on a front toward the mirror. (If a homemade ripple tank is used, the wave generator should be moved up and down into the water to create uniform wave action.)

QUESTIONS FOR STUDENTS

1. What did you observe about water waves created by a pointed object? (The waves moved out in the form of concentric circles from the point of origin.)
2. What did you observe about waves created by a pointed object after they were reflected from the mirror? (The reflected waves moved as if a pointed object *behind* the mirror were creating them.)
3. In Procedure C, how did waves created by the generator compare with those reflected from the mirror? (The reflected waves had the same form as those created by the wave generator.)

INTERPRETATIONS

1. Waves carry energy, and the region of wave action represents a region of energy. The relatively calm water behind the mirror is a region of little or no wave energy. You may wish to compare the action of waves striking the mirror with that of waves striking a coastline. Stress that a calm body of water, lacking wave action, does not possess wave energy. Energy must be transferred to water from something else if waves are to be produced.

PROCEDURES

D. Set the metal mirror at about a 45° angle in relation to the wave generator. Create a series of waves moving on a front toward the mirror.

QUESTIONS FOR STUDENTS

4. In relation to the mirror, how does the angle of the reflected waves compare with the angle of the incoming waves from the generator? (The angle between the mirror and the direction of the reflected waves is equal to the angle between the mirror and the direction of the incoming waves.)
5. In what way is the reflection of water waves from a mirror similar to the behavior of light in the same circumstances? (Light striking

a mirror at a given angle is reflected at the same angle. Water waves behave in the same way.)

PROCEDURES

E. Replace the straight mirror with a curved mirror. The top edge of the curved mirror should be at least ½ cm above the surface of the water. Using the generator, create a series of waves directed toward the *concave* side of the curved mirror. (The reflected waves should come together at a point just in front of the mirror.)

INTERPRETATIONS

2. Students may suggest that light waves would also have come together at a point in front of a curved mirror. Ask how they might verify this. Their first problem will be to locate a curved mirror that reflects light. Encourage students to devise their own method of investigation. If they are unable to suggest a suitable experimental design, the following "Optional Investigation" will demonstrate the behavior of light reflected from a curved mirror.

OPTIONAL INVESTIGATION

MATERIALS (per team)

Piece of aluminum, cut from the bottom of a disposable aluminum pie plate (about 8 x 4 inches). The aluminum must be as smooth as possible. Heavy-duty aluminum foil works well if it is not wrinkled

Lamp with 50-watt (or larger) bulb

Sheet of white paper

PROCEDURES

A. Shape the aluminum strip so it has a smooth, concave surface and place it on edge on a sheet of white paper.

B. Hold the lighted bulb about 6 inches from the curved surface. Adjust the distance until the reflected rays of light focus at a point.

INTERPRETATION

Discuss the behavior of water waves and light reflected from similar surfaces. We suggest that formulation of a wave model of light be postponed until the end of this section.

Figure 12 • 17. What happens to a wave when it strikes shore rocks?

INVESTIGATION 12.8: Changing the Direction of Wave Travel

A change in water depth can affect waves traveling across the region where the change occurs. Compare the effect you observe in water waves with the change for a beam of light passing from one transparent substance into another.

MATERIALS (per class)

- Ripple tank with generator
- Triangular metal "prism"
- Round metal "lens"

PROCEDURES

A. A triangular metal "prism" has been placed in front of the ripple tank wave generator. Carefully observe and record any change in the direction of waves as they move beyond the prism.

B. The metal prism has been replaced by a round metal "lens." Observe and record any change in the direction of the waves as they move over and beyond the lens.

INTERPRETATION

Compare changes in direction observed in water waves with the bending of light passing from one substance to another (see Investigation 12.6).

INVESTIGATION 12.9: Interference of Water Waves

The term *interference* is used to describe what happens when several waves meet and form new patterns. Careful observation should show you what an interference pattern looks like.

MATERIALS (per class)

Ripple tank with generator
Interference plate
Masking tape

PROCEDURES

A. Observe wave action that results from a point source.
B. Now observe wave interference, as waves generated from two different points meet. Record your observations. If necessary, draw a diagram in your notebook that represents the effect of wave interference.
C. An interference plate has been placed in the ripple tank. The plate is similar to a metal mirror, except that an opening has been cut in it, allowing waves to pass through at one point. Observe and record the appearance of waves as they strike the plate and travel through the opening.
D. Now there are two openings in the interference plate. Observe and record the interference patterns as waves come together after passing through the two openings.

INTERPRETATIONS

1. Compare the pattern of waves formed by a single opening in the interference plate (Procedure C) with the pattern of waves formed by a pointed object (Procedure A).
2. Compare the interference patterns formed by the merging waves that have passed through the two openings (Procedure D) with the merging waves formed by pointed objects at two locations (Procedure B).

INVESTIGATION 12.8: Changing the Direction of Wave Travel

(page 299)

Further support for a wave model is gained when students compare the refraction of water waves with the refraction of light.

MATERIALS

A baby-food jar lid will serve for the metal lens if it can be fastened to the bottom of the ripple tank (so the lens will not float). The metal prism and lens may be made from sheet metal. See Appendix D, "Equipment and Supplies for a Class of 32 Students," for ripple tank components (page 350).

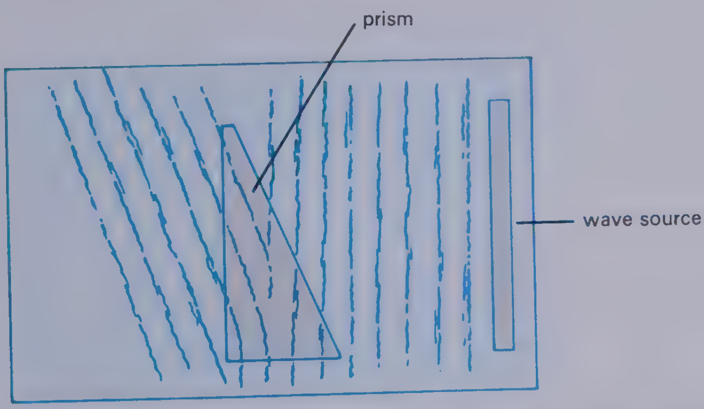


Figure T-12 • 6. Waves passing over a metal prism.

PROCEDURES

A. Place the metal prism in the tank so the edge facing the wave generator is at a 30° angle to the generator. It is critical that the prism be covered with water to a depth of less than 1 cm. The exact amount will vary according to the structure of the ripple tank, the intensity of the projector light, and the type of wave generator. Practice generating waves so they pass over the prism and emerge traveling in a different direction, as illustrated in Figure T-12 • 6. Add or remove water until the water depth over the prism yields good results.

B. Waves passing over a lens should bend so they reach a focal point (for an instant) on the side opposite the source of the waves

(Figure T-12·7). As with the prism, the depth of water covering the top of the lens is a critical factor.

INTERPRETATION

Students should observe that water waves bend in a manner similar to the bending of light.

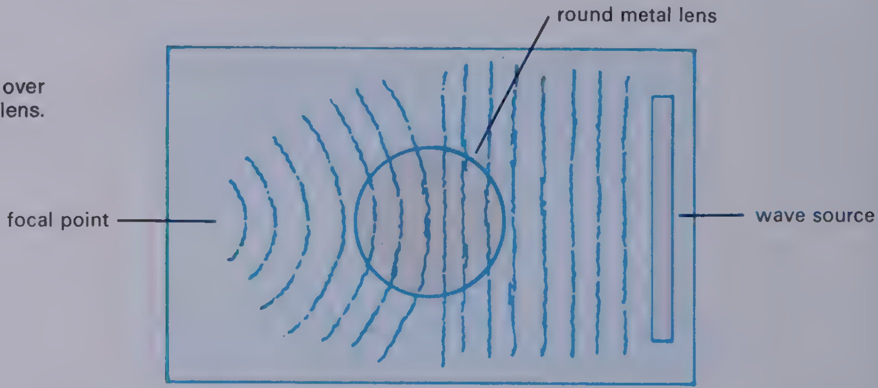


Figure T-12 • 7. Waves passing over a round metal lens.

INVESTIGATION 12.9: Interference of Water Waves

(page 300)

It may be difficult for students to see the interference patterns created when two water waves merge. But observing this phenomenon is essential to the development of a wave model of light.

PROCEDURES

A. Dip a finger into the water in the ripple tank to demonstrate the motion of waves generated from a single point.

B. Dip two fingers (about 3 inches apart) into the water to demonstrate interference patterns in waves originating at two different points.

C. Place an interference plate in the ripple tank (see Appendix D). Cover one opening with masking tape. Create a wave front with the generator and ask students to observe waves as they emerge from one opening.

D. Remove the masking tape and allow waves to pass through both openings.

INTERPRETATIONS

1. Waves generated at a single point and waves emerging from one opening in the interference plate behave in the same way. In other words, it appears that the opening causes the same kind of wave pattern that a pointed object does.
2. The same interference patterns should be observed. Waves emerging from one opening should look like those shown in Figure T-12 • 8.

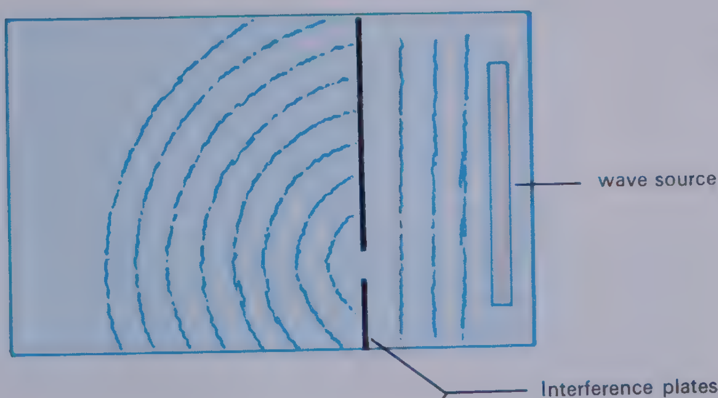


Figure T-12 • 8. Interference plate with one opening.

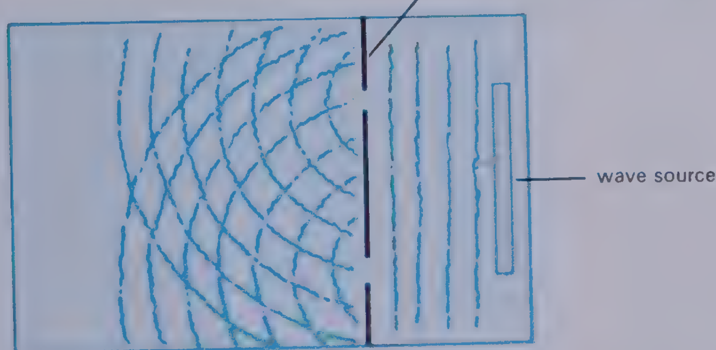


Figure T-12 • 9. Interference plate with two openings.

Waves emerging from both openings of the interference plate should exhibit interference patterns similar to those shown in Figure T-12 • 9. Where crests from one point meet crests from the other point, they appear extra bright; where troughs meet with troughs, extra dark. In regions where the brightness did not change, crests from one source met troughs from another source, and wave energy was at a minimum. These narrow regions of minimum disturbance should be visible, radiating out from both openings.

INVESTIGATION 12.10: Viewing Light through Small Openings

You have observed interference patterns in water waves. You have also observed that light and water waves are reflected and bent in similar ways. Although there appear to be similarities between water waves and light, there are also differences. For example, you have never seen light move up and down like the water waves in a ripple tank. But you might be able to see a pattern of energy distribution for light that resembles the energy distribution for water waves. Copy Figure 12 • 18 in your notebook. Fill in the blank spaces by describing the amount of light you would expect for each amount of energy.

Figure 12 • 18.

	ENERGY			
	None	*Small amount*	*Moderate amount*	*Large amount*
Water	Calm	Rippled	Waves	Large Waves
Light				

MATERIALS (per student)

- Light source
- Aluminum foil with two small openings
- Diffraction grating

PROCEDURES

A. Handle the aluminum foil with care—it tears easily. Examine it carefully. You will find two very small openings, about 1 mm apart, in the foil. What do you think you would see if you were to view a light source through the two openings? Would you see two beams of light? One beam of light? *Do not perform Procedure B until you have recorded your prediction.*

B. Hold the foil at arm's length between your eyes and the light source. You may be able to see the two openings. Now bring the foil close to one eye, so that the two openings appear to blend into one. Rotate the foil while looking at the light through the openings.

INTERPRETATIONS

1. Describe what you observed through the openings while holding the foil close to one eye. Did you predict the result correctly?
2. Suggest an explanation for your observations. Relate your explanation to what you know about water waves.
3. Can your observations be explained with a particle model of light?

PROCEDURES

C. The diffraction grating has many openings so small and so close together that you cannot see them. The openings are narrow slits in the plastic film. There are 13,400 slits per inch! What do you think you would see if you were to look at the light source through the diffraction grating? Do not perform Procedure D until you have recorded your prediction.

D. Hold the diffraction grating close to your eye and look at the light source. Then look slightly to the left or right of the light source to see the effect produced by the diffraction grating.

INTERPRETATIONS

4. Did your observation agree with your prediction?
5. Describe as accurately as possible what you observed.

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INVESTIGATION 12.10: Viewing Light through Small Openings

(pages 301–302)

The existence of interference patterns in light further strengthens the wave model. Diffraction grating used to observe this phenomenon will be used later to analyze light.

MATERIALS

Several different light sources may be used. A 25-watt (unfrosted) showcase bulb will serve as a single light source for the entire class. Ordinary flashlight bulbs will be adequate for viewing at short distances.

The aluminum foil with two openings (an interference plate) can be prepared in several ways. The openings, or slits, should be about 1 mm apart. It is possible to cut slits in a piece of foil with two razor blades taped together. The following method has also proved successful in this investigation:

Obtain a wood screw that has from 30 to 40 threads per inch. Lay the foil on a smooth wood surface. Hold the screw firmly on the foil and cut slits by pulling the threads through a distance of about 2 inches over the foil. Then cover all but two of the slits with cardboard, fastened with masking tape.

Instead of foil, you can use a small piece cut from the bottom of a disposable aluminum pie pan. The screw can be placed on the aluminum and struck with a hammer. The result is a sturdier product that is less likely to be damaged. As with the aluminum foil, the piece cut from the pie pan should have all but two slits covered.

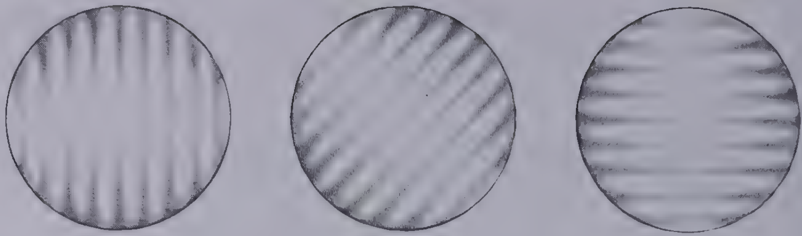
Diffraction grating slides should be taped over a hole cut in a file card or a square of construction paper. This will keep the plastic flat, easier to hold, and increase its durability. Mounting a piece of diffraction grating between two microscope slides also yields a durable product. The glass protects the plastic grating from scratches.

PROCEDURES

A. Have students record their prediction before carrying out Procedure B. It is not possible to guess what students will predict. Accept all suggestions, but withhold "answers."

B. When the aluminum foil is held at arm's length, the two slits should be clearly visible. As the foil is moved close to the eye, light and dark bands should be seen. When the foil is rotated, the bands will also rotate (Figure T-12 · 10).

Figure T-12 • 10.



INTERPRETATIONS

1. Students should report seeing alternate dark and light lines.
2. Encourage students to suggest a possible relationship between the interference lines of light and the interference patterns of water waves. The dark lines represent regions of little or no energy; the light lines, regions of high energy.
3. Students probably will not be able to explain their observations in this way. The question should be left open. It would be difficult to explain how "bullets" of light energy could account for the many dark and light lines seen through the slits in the aluminum foil.

   At this point suggest that if water waves produce interference patterns, light may exhibit wavelike behavior; therefore, interference patterns *could* be responsible for the light and dark lines. Stress that these assumptions are based upon a *model* to explain the behavior of light, rather than upon *facts*.

PROCEDURES

C. Students should predict (hypothesize) what they will see when looking at the light source through the diffraction grating. They may suggest that many more dark and light lines will be seen. Some students may be familiar with diffraction grating, and they may suggest that different colors will be observed. Encourage expression of all opinions, but withhold answers at this time.

D. Students should observe a "rainbow" of colors. Ask them to explain this in terms of energy. Guide them to suggest that the different colors represent different amounts of energy. Refrain from giving a quantitative value to the different energy levels.

INTERPRETATIONS

4.–5. Student responses will vary. Encourage students to describe their observations as completely and as accurately as possible.

We hope this series of investigations will lead students to a wave model of light as a possible explanation for certain kinds of light be-

havior. Both a particle (quantum) model and a wave model are used by scientists to describe light energy.

Students should realize that white light is composed of different colors of light having different amounts of energy. This can lead to a study of the electromagnetic spectrum—which includes not only visible light, but also radiant energy given off in the form of X rays, ultraviolet waves, and radio waves.

Some details of the electromagnetic spectrum will be discussed in Section Thirteen. Other, more detailed, studies of the electromagnetic spectrum should be reserved for future courses.

SUPPLEMENTARY MATERIALS

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FILMS

How to Bend Light. Encyclopaedia Britannica Film #1878. 11 minutes. Color. Use at the end of the section to reinforce lessons about refraction and reflection and the effects of various media on the path of light.

Waves and Energy. Encyclopaedia Britannica Film #1874. 11 minutes. Color. The film demonstrates that sound, light, and radio waves have common characteristics. It will reinforce the particle and wave models for light. Use at the completion of this section.

FILM LOOPS

An Inquiry into Light: Testing the Particle Model. Interaction Film Loops, Inquiry in Physical Science. Chicago: Rand McNally & Co., 1972.

An Inquiry into Light: Testing the Wave Model. Interaction Film Loops, Inquiry in Physical Science. Chicago: Rand McNally & Co., 1972.

SUGGESTED ACTIVITIES FOR TESTING LABORATORY SKILLS AND TECHNIQUES

INVESTIGATION 12.4
Use pins to locate an image behind a mirror.

INVESTIGATION 12.5
Use a protractor to measure angles.

INVESTIGATION 12.6
Use pins to locate lines of sight through transparent substances.

INVESTIGATION 12.7
Locate an image for reflected waves in a ripple tank.

INVESTIGATION 12.8
Recognize wave refraction in a ripple tank.

INVESTIGATION 12.9
Recognize an interference pattern in a ripple tank.

INVESTIGATION 12.10
Use a diffraction grating to observe the spectrum of white light.

SECTION THIRTEEN

Energy Conversion

SECTION THIRTEEN

Energy Conversion

(pages 305–326)

Preview

This is the last section containing laboratory investigations. The investigations dealing with energy conversion should help students to better understand the modern model for matter and for the interaction of matter and energy.

You will probably want to spend time in class discussion after finishing the section. In this way you can "tie up" loose ends and perhaps discuss with your students what knowledge they have gained, in an overall sense, as a result of using the IME program.

A study of the visible spectrum and its relationship to chemical reactions provides an opportunity for students to use the model of atomic structure developed in Sections Three and Four.

Energy conversions from heat, light, and chemical energy to electricity are studied. Energy conversions within the electromagnetic spectrum and in nuclear reactions are also discussed. However, we have avoided the use of nuclear reaction equations and investigations with radioactive materials in the belief that these activities more properly belong in a senior high school chemistry or physics class.

There are five investigations, an Inquiry Demonstration, and several full color inserts in this section. The investigations should prove both interesting and challenging to most of your students.

The next (and last) section of the revised IME program, "Science and Humanity," is an essay dealing with many of the problems facing the human race with emphasis on the roles science and technology must play to solve these problems. While there are no investigations, a number of questions are brought up and students are asked to reflect upon them now and in the future.

Section Thirteen opens with an infrared photograph of the Phoenix, Arizona, area, taken in 1969. The city itself is the gray area surrounded by red in the upper left quadrant of the photo. The red areas are farm

fields. Infrared photography, a form of energy conversion itself, has become a useful tool in energy studies, since it can detect differences in energy use, at great distances.

LEARNING OBJECTIVES

Given the opportunity to inquire, to investigate, to interpret data, and to offer hypotheses about the activities in this section, most students should be able to—

- Demonstrate or explain several examples of energy conversion;
- Analyze and interpret data which illustrate the behavior of colored light (reflected and absorbed);
- Use diffraction grating to analyze the transmission or absorption of white light by color filters;
- Offer hypotheses to explain the various colors that result from flame tests of chemical compounds;
- Recognize that the color given off by a burning sample can help identify the positive ion of the sample;
- Explain the relationship of radiant heat and light to the rest of the electromagnetic spectrum;
- Incorporate information about electron energy levels into their model for the structure of matter;
- Associate the energy of electron flow in a light bulb with the brightness of the light;
- Offer hypotheses which explain the electron flow which results when dissimilar wires are twisted together and heated;
- Describe and associate bright line spectra with the energy level changes of excited electrons;
- Describe the conditions necessary to use the potential chemical energy of chemicals to produce an electron flow;
- Incorporate the electron movements associated with heating and electric currents into their model for the interaction of matter and energy.

Energy is needed for work to be done. A major activity in the development of civilization has been the search for sources of energy. The first reliable supply was man himself. Domesticated animals were the next source of energy to be used for work. However, our industrial society is based on energy sources more advanced than muscle power.

Today, society is seeking new sources of energy as present sources prove inadequate in meeting man's needs. Most of the energy we use comes from burning fuel. The energy is usually changed from heat to some other energy form that is more convenient to use. For example, burning fuel may be used to produce steam to run a generator that produces electrical energy. In homes, offices, factories, and schools, this electricity is converted into other forms of energy. It is likely that the light you are using to read this book was produced by a series of energy conversions like the ones just described. Earlier in the course, you studied several different forms of energy: chemical, heat, light, and motion. In this section, the emphasis will be on changing energy from one form to another through interactions with matter.

INVESTIGATION 13.1: Color—Reflection and Absorption

As you have seen, the behavior of light is complex. White light passing through a diffraction grating acts, in some respects, like waves. But white light reflected from a mirror behaves more like a stream of particles.

Now you are to investigate the reflection of light from surfaces having different colors.

Why do objects appear to have different colors? How is color related to a model of light? You will now examine these questions.

MATERIALS (per team)

Viewing box with light source and filter holder (Figure 13 • 1)
Colored filters (red, blue, green, and yellow)
Colored squares mounted on black paper (Figure 13 • 2)

To construct the viewing box shown in Figure 13 • 1, the following materials will be needed:

Shoe box
Cardboard packing box (about 2 feet on each side)
110-volt light socket, cord, and plug
110-volt, 25-watt unfrosted light bulb
Masking tape
4 sheets of colored cellophane (red, blue, green, and yellow)
4 pieces of cardboard (6 x 9 inches)
Sharp knife

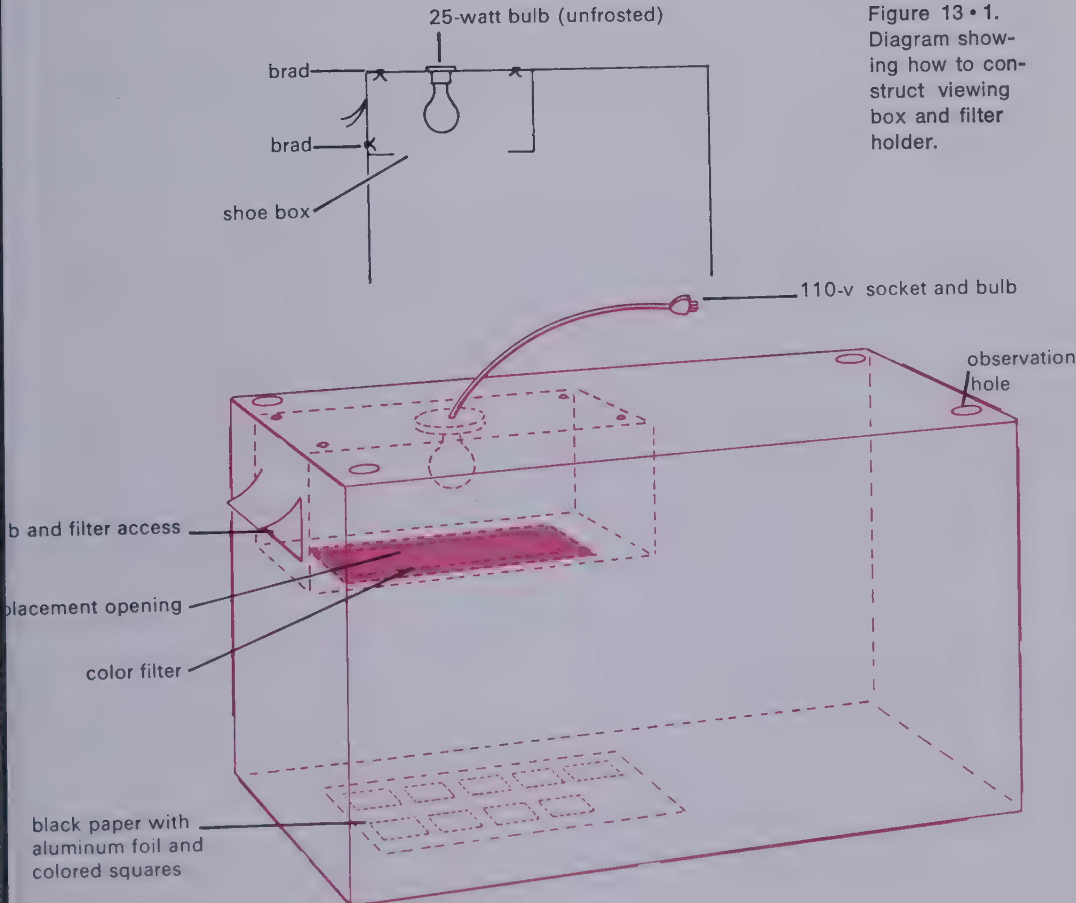

Figure 13 • 1. Diagram showing how to construct viewing box and filter holder.

Figure 13 • 2. Black paper with aluminum foil and colored squares to be used in the viewing box.

The box is designed so that a variety of color samples can be examined with white light and with light that has passed through colored filters. The bottom of the large box should be open, so the black paper with colored squares (or other objects) can be placed in position for viewing. *Check with your instructor before connecting the light source to an electrical outlet.*

Each piece of cardboard should be large enough to cover the opening in the bottom of the shoe box. Cut a hole 4 x 6 inches in each piece of cardboard and in the bottom of the shoe box. Fasten colored cellophane over each cardboard frame with tape.

Cut the flap allowing access to the bulb after you have assembled the two boxes. Finally, cut the opening for the bulb socket and insert the bulb through the access flap. Fasten 1-inch squares of colored paper and aluminum foil to a piece of black paper (10 x 4 inches) as shown in Figure 13 • 2.

PROCEDURES

A. Place the black paper with squares under the viewing box, as shown in Figure 13 • 1. *Before* performing Procedure B, predict which of the two aluminum squares will appear brighter when viewed under white light.

B. View each of the squares under the white light. Have each member of the team look through all of the observation holes. Record the appearance and color of each square.

INTERPRETATIONS

1. Which appears brighter—the smooth aluminum foil or the wrinkled foil? From your model of light, explain the appearance of the two aluminum squares.
2. Do the pieces of colored paper appear to change color when viewed in the box?

PROCEDURES

C. Place the red filter over the opening in the shoe box. Observe and record the appearance of each colored square. Repeat with each of the other filters, recording your observation in a table similar to the one shown in Figure 13 • 3.

INTERPRETATIONS

3. Explain the observations recorded in Procedure C.
4. Describe the interaction between matter and energy you observed in this investigation.

Color of Paper Square	*Color of Paper Squares Under Filtered Light*				
	No Filter	Red Filter	Blue Filter	Green Filter	Yellow Filter
Red					
Orange					
Yellow					
White					
Black					
Blue					
Green					

Figure 13 • 3.

ON YOUR OWN: Changing Colors

Use a light box and color filters to observe color photographs or pictures from magazines.

Design an investigation to observe the appearance of the colored paper squares illuminated by mixtures of colors of light.

INVESTIGATION 13.1: Color—Reflection and Absorption

(pages 305–326)

In this investigation students observe interactions between matter and light energy in which colors are controlled by pigments. Students should understand that the response (reflection, absorption, transmission) depends on the color of the incident light and the properties of the pigment. The "Inquiry Demonstration: Examining the Spectrum of Light Passed through a Filter" (pages 309B–309C) is an integral part of Investigation 13.1 and provides a basis for answering Interpretation 3. The demonstration should be performed before you discuss Interpretation 3 with your students.

MATERIALS

Details of the viewing box are shown in Figure 13 • 1 so that teams may construct their own. Make test observations of the colored paper before assigning this investigation to be sure the samples you have selected give suitable results with your light sources. Some teams may require assistance. If it is convenient to darken the room, you may want to do this investigation as a class activity, with large squares of paper taped to the blackboard. A small colored light source can be used to illuminate one piece of paper at a time.

PROCEDURES

A. Students are apt to predict that the smooth foil will reflect light better than the wrinkled foil.

B. No comment.

INTERPRETATIONS

1. From most of the observation holes the wrinkled foil will appear brighter than the smooth foil. Encourage students to explain this result. (Light striking the smooth foil is reflected in only one direction. Light striking the wrinkled foil is reflected in many directions, so the viewer can see it better.)
2. No, the squares of paper will have the same appearance inside the box as they did outside it.

PROCEDURES

C. For best results you may have to use several thicknesses of cellophane in each filter. Apparent colors of paper squares in filtered light are given in Figure T-13 • 1.

Figure T-13 • 1.

Color of Paper	*No Filter*	*Red Filter*	*Blue Filter*	*Green Filter*	*Yellow Filter*
Red	Red	Red	Black	Black	Reddish yellow
Orange	Orange	Red orange	Black	Black	Yellow orange
Yellow	Yellow	Red orange	Blue	Green	Yellow
White	White	Red	Blue	Green	Yellow
Black	Black	Black	Black	Black	Black
Blue	Blue	Black	Blue	Green	Yellow green
Green	Green	Black	Blue	Green	Yellow green

NOTE: *Manufacturers may use different combinations of dyes to produce a particular color. The papers you use may be different from the papers used for the sample data. This would affect the colors seen in filtered light. For example, if the red paper you use has some blue pigment in it, some blue light will be reflected. Some students may be color-blind; their results will differ from those of others.*

INQUIRY DEMONSTRATION: Examining the Spectrum of Light Passed through a Filter

(Teacher Only)

The demonstration should precede a discussion of Interpretation 3.

NOTE: *You may wish to have each team perform this demonstration. Three things can happen when light strikes a surface: (1) it may be reflected, (2) it may be transmitted or allowed to pass through, and (3) it may be absorbed. The factors that determine the outcome are the composition of the surface and the colors that make up white light. The composition of filters is such that some light energies are transmitted and some are absorbed.*

PROCEDURE

Cut a hole 1 cm in diameter in the center of each end of a shoe box. With tape, fasten a diffraction grating over one hole. Shine the beam

of a penlight or small flashlight through an opening in the opposite end of the box. Ask students to look through the diffraction grating to observe the spectrum. Then place filters, one at a time, between the diffraction grating and the viewers' eyes.

The red filter should allow red light and some yellow light to pass through, but it should block out (absorb) the green and blue regions of the spectrum. Similarly, the other filters should transmit light of their own color and the adjacent colors in the spectrum; they should absorb light in the remainder of the spectrum. After this activity students should have a better understanding of the effect of a filter and the composition of light passed through a filter.

INTERPRETATIONS (Investigation 13.1)

3. Students should understand that filters allow certain light energies to pass through them, while reflecting or absorbing others. Each filter is named for the color of light that is able to pass through it in the greatest amount.

   Each square of paper is named for the color of the light it reflects in the greatest amount (except for white paper, which reflects all colors, and black paper, which reflects very little light of any color).

   The red filter allows red light to pass through. This light is reflected by the red, orange, yellow, and white squares of paper. (Most orange paper has some red pigment in it, and most yellow paper has quite a bit of white-reflecting surface.) The black, blue, and green squares appear black when the red filter is used because they are not capable of reflecting red light.

   The blue filter allows only blue light to pass through. The red, orange, and black squares look black under the blue filter because they are not able to reflect blue light. And yellow, white, blue, and green squares appear blue because of the blue-reflecting pigments in the blue and green squares and the white-reflecting surfaces in the yellow and white squares.

   In addition to green light, the green filter allows some yellow and some blue light to pass through. The red, orange, and black squares are not able to reflect these colors, so they appear black. The white, yellow, blue, and green squares can reflect these colors, and appear green.

   The yellow filter allows all colors to pass through, but it absorbs less light in the yellow region than in the other regions. Therefore all the squares except black reflect some light.

   Have the students use diffraction grating to examine the light that passes through each filter. When they see that filters let

through a *band* of colors rather than a single, "pure" color, this interpretation may be easier for them to discuss.

4. Students should suggest that, depending on the properties of a particular sample of matter, light which strikes it may be reflected and/or absorbed and/or transmitted. They should also point out that a sample may interact differently with different colors of light.

   You may want to remind students that in Investigation 11.7 they observed one effect (heating) that occurs when light is absorbed by matter.

ON YOUR OWN: Changing Colors

(page 309)

The glossy surfaces of photos and pictures reflect more light than rough textured construction paper. However, the results should be similar to the results of Procedure C, Investigation 13.1.

The design for mixing colors could utilize a separate light source for each filter, or two filters side by side under one light source.

INVESTIGATION 13.2: Color and Chemicals

Some chemical compounds have distinct colors. Others are white or colorless. In this investigation, heat energy will be added to several chemicals. Try to observe an interaction between heat and matter that could be used to identify chemicals.

MATERIALS (per team)

Burner (gas or alcohol)

MATERIALS (per class)

9 nichrome wire flame testers

Small amounts of each of the following crystals:

- Copper chloride—$CuCl_2$
- Copper nitrate—$Cu(NO_3)_2$
- Copper sulfate—$CuSO_4$
- Potassium chloride—KCl
- Potassium bromide—KBr
- Potassium sulfate—K_2SO_4
- Sodium chloride—$NaCl$
- Sodium bromide—$NaBr$
- Sodium sulfate—Na_2SO_4

PROCEDURES

A. Label each of the nichrome wire flame testers with the name of one of the chemicals to be tested. Each chemical must be used *only* with the tester carrying its name.

CAUTION: *Keep your eyes as far as possible from the flame when testing the chemicals. Wear safety goggles. The crystals may shatter and cause injury.*

B. Place one or more crystals of a chemical in the loop at the end of the nichrome wire. Hold the loop near the tip of the burner

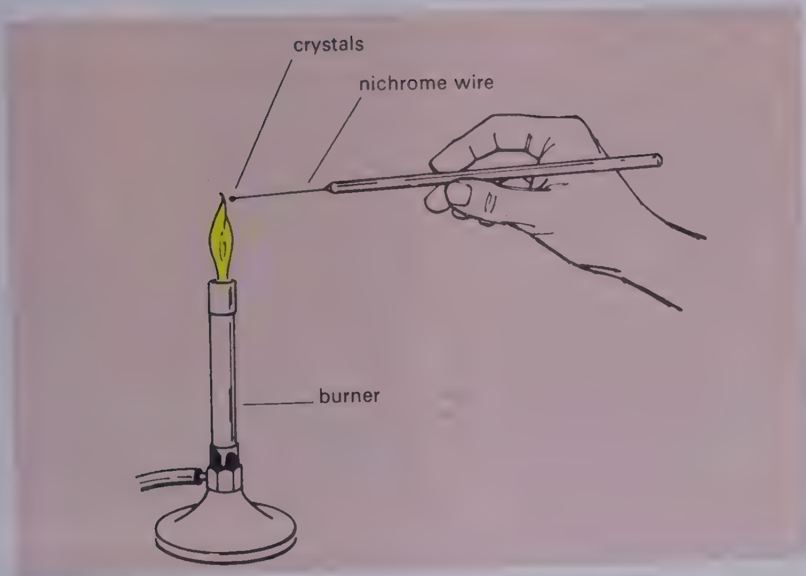

Figure 13 • 4. Setup for Procedures B and C.

flame until the crystals are used up (see Figure 13 • 4). Observe the color of the flame. Record your observation on a table similar to the one shown in Figure 13 • 5.

C. Exchange nichrome wire testers and chemicals with other teams. Continue testing until all teams have observed the heating of each chemical.

Figure 13 • 5.

Chemical	*Color of Flame*
$CuCl_2$	
$Cu(NO_3)_2$	
$CuSO_4$	
KCl	
KBr	
K_2SO_4	
NaCl	
NaBr	
Na_2SO_4	

INTERPRETATIONS

1. Can you find any relationships between flame colors and the chemical formulas?
2. Which ion in each of the chemicals tested appears to be responsible for the flame color given off by that chemical?
3. What do you think is the source of energy that produced the color change?
4. Develop a model that could explain the color changes. Include evidence gathered from previous investigations to support your model.
5. See Figure 13 • 6 and answer the question.
6. See Figure 13 • 8 and answer the question.

Figure 13 • 6.
The light emitted by each of these three flames has a color characteristic of the elements present. From the results of Investigation 13.2, can you tell which flame was produced by NaCl, by $Cu(NO_3)_2$, and by KCl?

Energy Conversion and Electricity

Most of us take for granted the electrical energy used to light our homes and run electrical appliances. Giant hydroelectric and steam generating plants convert the energy of motion of moving water and the stored energy of fuels into electricity for use in homes and industry.

Flashlights and portable appliances are powered by batteries. In them, electrical energy must be converted from some other form of energy. It is convenient to transport energy in the form of electricity and then reconvert it into light energy, mechanical energy, heat energy, and other forms of energy useful to man.

You have already studied many aspects of energy conversion and have attempted to develop models that explain the results of your investigations. You will examine some additional features of energy conversion in the next series of investigations. Though each investigation is different, the results of each can be explained using the models you have already constructed. Figures 13 • 8*A*, *B*, and *C* illustrate one form of energy conversion.

INVESTIGATION 13.3: Electricity and Light

You have seen how electrical energy can be converted into light energy (Investigation 13.1). This investigation will focus on a related (but different) form of energy conversion. Use your model for the structure of matter to explain your observations.

MATERIALS (per team)

Silicon solar cell
Milliammeter
Light source (unfrosted 25-watt showcase bulb with a long element)

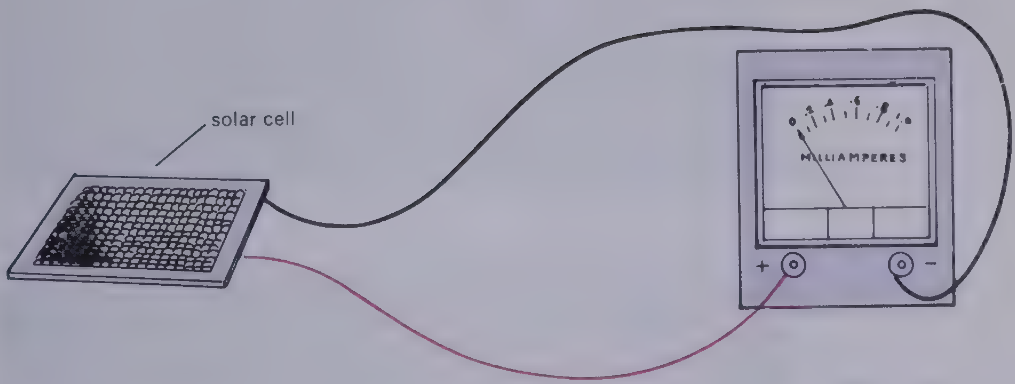

Figure 13 • 7.
Silicon solar cell and milliammeter.

PROCEDURE

Hold the silicon solar cell so that it faces the light source (see Figure 13 • 7). Observe the movement of the milliammeter needle. Vary the distance from the solar cell to the light source and record your observations.

INTERPRETATIONS

1. The needle indicates the flow of current—or, to be more exact, electrons—through the meter. What is the source of these electrons?
2. When no light strikes the solar cell, no electrons flow through the meter. When light shines on the solar cell, energy moves the electrons. Where does this energy come from?
3. What practical value might solar cells have in modern industry or scientific research?

ON YOUR OWN: Measuring Colored Light

Design an investigation to determine the effect of color filters on readings obtained from the solar cell. Try combinations of filters as well as single filters.

Figure 13 • 8. What form of energy conversion is being illustrated by these three photographs? How is the color of light related to the voltage?

INVESTIGATION 13.2: Color and Chemicals

(pages 310–312)

Students have now seen that white light viewed through a diffraction grating is composed of various colors. From this observation students should grasp the idea that different colors of light may be associated with different light energies. The purpose of this investigation is to show that a specific chemical absorbs only a certain amount of energy from a flame and then gives this energy back as a particular color. Develop the idea that each color is associated with a different and specific amount of energy.

MATERIALS

The nine chemicals listed are readily available and give distinctive colors. Your students may test other chemicals in the same manner. Sodium ions are always present on students' hands; if their hands touch the wires, the next flame test will show the yellow color characteristic of sodium. It is critical that each nichrome wire flame tester be used with only one chemical. Nichrome wire flame testers can be purchased from commercial supply houses.

It is easy to construct a tester by fastening a 3-inch piece of nichrome wire to a round wooden handle with masking tape. A pencil or wooden dowel (cut into 4-inch lengths) will serve as the handle. A small V-shaped loop at the end of each wire will help to hold the crystals.

PROCEDURES

A. No comment.

B. Students should copy the table in their notebooks and record their observations for future reference.

C. Every student should have the opportunity to observe the flame color from each chemical; the chemicals and nichrome wire flame testers should be exchanged among teams.

INTERPRETATIONS

1. Copper compounds produce a blue green flame; potassium compounds, a pale violet flame; sodium compounds, a yellow flame.
2. The positive ion is responsible for the color of the flame. The negative ions present do not affect the flame color.
3. The immediate energy source is the burner flame.
4. Students may have difficulty in developing a model to explain the color changes. Their model should take into account the different

amounts of energy present in particular colors of light. Electrons are "excited" to higher energy levels by heat. They absorb energy when they are excited to higher energy levels and give off energy when they drop back down to lower energy levels. This energy is given off as light, and the colors of light for each element depend upon the energy levels that the electrons "drop" through. Because there are so many atoms present in any sample large enough to test, some of them are being excited while others are losing their stored energy. As long as these processes continue, light is given off. Each positive ion gives off its own characteristic color of light. This is evidence that electrons in specific atoms can accept only a certain amount of energy from the flame.

5. *a.* Sodium chloride.
   b. Copper nitrate.
   c. Potassium chloride.
6. Electrical to light. Low voltage gives a reddish light, medium voltage a yellowish light, and higher voltage a white light.

INQUIRY DEMONSTRATION: Bright Line Spectra

(Teacher Only)

Students will see the difference between the continuous spectrum and the spectral lines unique to certain elements.

MATERIALS

Neon bulb
Gas-filled discharge tubes (if available)
Diffraction grating

PROCEDURES

The room should be as dark as possible. Individual students should take turns observing the neon bulb through the diffraction grating, recording their observations in their notebooks. If the room cannot be sufficiently darkened to give good results, the neon bulb can be placed in a dark box (Figure T-13 • 2). Have students hold the grating up against a hole cut in the end of the box so that they can observe and record the appearance of the bright line spectrum. If the gas tubes are available, repeat this part with each discharge tube.

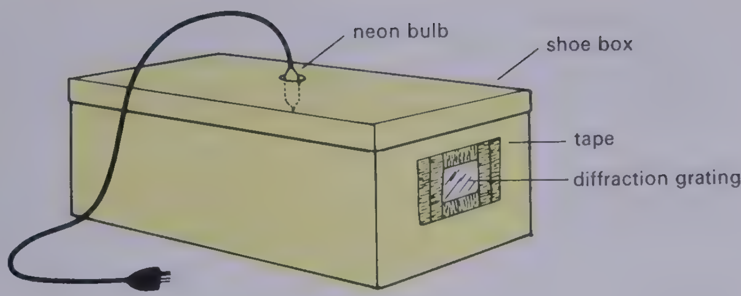

Figure T-13 • 2.

INTERPRETATION

Ask students to compare their observations of a neon bulb with their observations of an ordinary incandescent bulb when viewed through the diffraction grating.

When an incandescent tungsten light source is viewed through a diffraction grating, the students can observe that all colors are present in "white light." Therefore all different light energies are present. With neon and other gas-discharge tubes, not all colors will be observed, indicating that only some light energies are present. A model that could explain this is as follows: Electrons in the atom are "excited" to higher energy levels by the electricity. Then, as the electrons move to regions nearer the nucleus, their energy is released. This could be correlated with the observations in the preceding investigation, where chemical compounds gave off different colors in a flame. Now would be an appropriate time to review the atomic model presented in Section Three, "The Structure of Atoms," where we proposed that electrons in different regions of an atom have different amounts of energy. And the transition from one region to another region represents a gain or loss of energy, depending upon the direction of the transition.

INVESTIGATION 13.3: Electricity and Light

(pages 314–315)

This investigation provides direct evidence that light can cause some electrons in atoms to move out of an electron cloud region and travel through the wires and meter.

MATERIALS (per team)

The milliammeter should be 1 milliampere full scale. See Figure 13 • 8 for details of assembling the apparatus.

Inexpensive solar cells are fragile and should be handled with care.

PROCEDURE

If light striking the solar cell does not cause a deflection of the milliammeter needle, reverse the wire connections on the meter.

INTERPRETATIONS

1. The material in a silicon solar cell has been prepared in such a way that light falling upon it causes electrons around the nuclei of some atoms to be removed and driven through an electrical circuit.
2. The energy comes from the light source. Electrons flow through a meter and do work against a spring in the meter. Thus light energy has been changed to electrical energy.
3. The question requires some research of current literature by students. Solar cells are used to charge batteries in space vehicles and as components in some telephone equipment.

INQUIRY DEMONSTRATION: The Inverse Square Law

(Teacher Only)

This investigation may be difficult for some students.

MATERIALS

A meterstick and the materials used in Investigation 13.3 will be needed.

PROCEDURES

Darken the room. Gradually increase the distance between the silicon solar cell and an unfrosted light bulb. Students should observe and record the meter reading at various distances. They can observe the relationship between light intensity and distance if the data is graphed. Have them plot the meter reading (light intensity) on the vertical axis and the distance on the horizontal axis.

The completed graphs will reveal an inverse proportion: as distance increases, intensity decreases. Numerical analysis shows that the inten-

sity depends on the square of the distance. This is called an *inverse square relationship*, and it is characteristic of all radiant energy—energy that radiates outward in all directions from a central point. Forms of energy showing this relationship include heat, sound, light, and X rays.

ON YOUR OWN: Measuring Colored Light

(page 315)

The color filters from Investigation 13.1 or colored cellophane can be used. The background reading from room light can be eliminated by darkening the room or by using a box as a light shield. Stacking filters of the same color results in a gradual decrease in meter reading. Stacking filters of different colors produces a larger decrease in the reading.

Since solar cells respond to infrared as well as to visible light, there will probably be a small reading even when all color filters are used simultaneously.

INVESTIGATION 13.4: Heat and Electricity

Another form of energy conversion can be illustrated by heating two different metals that are connected to a meter. As you carry out this investigation, try to relate the energy effects to your model of the structure of matter. Your final goal is to understand the relationship of matter and energy. To do this, you must work your knowledge of energy into your atomic model.

MATERIALS (per team)

Alcohol burner
Candle
Copper wire
Nichrome wire
Matches
Milliammeter

PROCEDURE

A. Twist the ends of the bare copper wire and the nichrome wire together tightly (ten to fifteen turns) as shown in Figure 13 • 9. Connect the free end of the copper wire to the *positive* terminal of the meter. Connect the free end of the nichrome

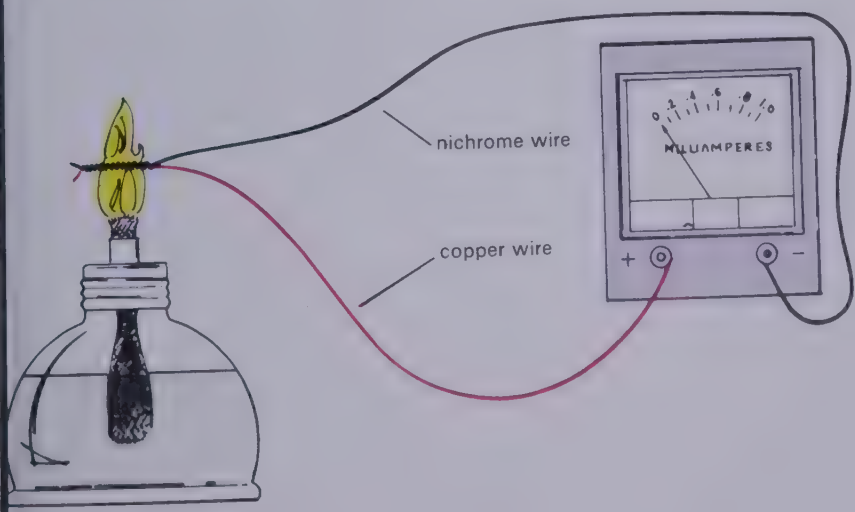

Figure 13 • 9. Setup for Procedure A.

wire to the *negative* terminal. Support the twisted ends of the wires over the flame of an alcohol burner. Heat the wires to red hot. Observe and record any movement of the meter indicator in your notebook.

B. Hold the twisted ends of the wire in the flame of a candle. Record the meter reading.

C. List some other sources of heat you would like to test with the twisted wires. Check with your teacher before you try them.

INTERPRETATIONS

1. Explain, in terms of electrical energy, the effect of heating two different kinds of metal that are touching.
2. Suggest a use for devices such as the one used in this investigation. (The current generated is not sufficient to operate a light bulb or an electric motor.)

INVESTIGATION 13.4: Heat and Electricity

(pages 317–318)

The purpose of this investigation is to observe electric energy being generated when dissimilar metals in contact are heated.

MATERIALS

The nichrome wire should have a much smaller diameter than the copper wire. The following wire diameters have given good results: nichrome, 0.17 mm; copper, 1.3 mm.

If meters more sensitive than 1 milliampere full scale are used, a larger needle deflection can be observed.

PROCEDURES

A. If the needle is not deflected to the right, reverse the connections on the meter. The flow of electrical current through the meter should be almost 0.1 milliamperes when the wires are held in the alcohol flame. If a Bunsen burner is used, the flame may melt the wire.

B. No comment.

C. Some suggestions may not be practical. For example, a Bunsen burner may damage the wires; hot water is not likely to generate a detectable current. Try any safe suggestion.

INTERPRETATIONS

1. If, as a result of the increase in temperature, the electrons become more mobile in one of the metals than in the other, there will be a net flow of electrons in one direction.
2. While the device is not practical for generating large amounts of electrical energy, it could be used to measure the temperature of a flame.

INVESTIGATION 13.5: Chemical Potential Energy

Stored chemical energy may be released by causing chemicals to react. Natural gas reacts with oxygen, releasing heat and light. The white form of copper sulfate reacts with water, producing heat. Gasoline combines with air to supply energy.

In chemical reactions, electrons are rearranged, and some of the stored energy is released. This investigation may give you some direct evidence that chemical reactions involve electron rearrangements.

MATERIALS (per team)

- Paper toweling
- Test tubes, 2
- 50 ml of 1-molar copper sulfate solution
- Copper wire
- 50 ml of 1-molar iron chloride solution
- Iron wire
- Milliammeter
- Graduated cylinder (100 ml)
- Metric ruler
- Scissors

PROCEDURES

A. Pour the copper sulfate solution into one of the test tubes. Put one end of the copper wire into this solution. Pour the iron chloride solution into the other tube. Put one end of the iron wire into this solution. Label the tubes.

B. Connect the iron wire to the negative pole of the meter. Connect the copper wire to the positive pole of the meter. Observe the meter. (NOTE: *Meters are designed to have electrons flow* in *through the connection marked* — *and* out *through the connection marked* +.)

C. Cut a strip of paper toweling about 6 cm wide and about 16 cm long. Fold it in half (lengthwise) three times so that its

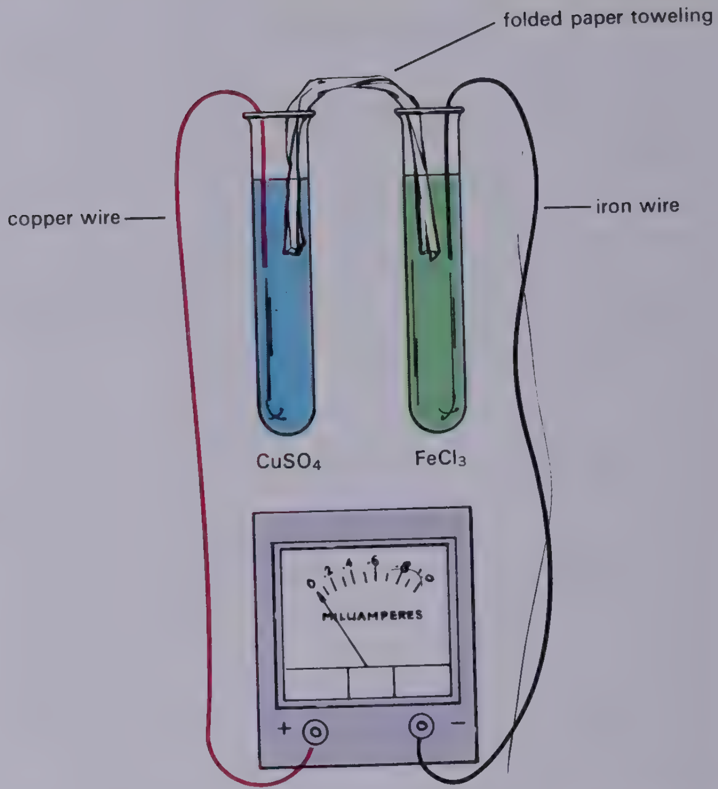

Figure 13 • 10. Setup for Procedure C.

final width is less than 1 cm. Bend it into a **U** shape. Insert one end of the paper toweling into the copper sulfate solution. Insert the other end into the iron chloride solution. (See Figure 13 • 10.)

When the toweling is completely wet, observe and record the meter reading.

D. To find out how concentration affects the reaction, you will need to dilute the solutions. Pour 10 ml of 1-molar iron chloride solution into the graduated cylinder. Add enough distilled water to make 100 ml of solution. Remove and discard the paper toweling connecting the two test tubes. Remove the iron wire from the test tube. Empty the test tube containing iron chloride and refill it with the diluted solution. Put the iron wire back into the test tube containing dilute iron chloride. Repeat Procedure C and record the meter reading.

E. Rinse the graduated cylinder. Pour 10 ml of 1-molar copper sulfate solution into the graduated cylinder. Add enough distilled water to make 100 ml of solution.

Remove and discard the paper toweling used in Procedure D. Remove the wires from the test tubes. Empty the test tubes. Pour 1-molar iron chloride solution into the test tube labeled *iron chloride* and replace the iron wire. Pour the diluted copper sulfate solution into the other test tube and replace the copper wire. Repeat Procedure C and record the meter reading.

INTERPRETATIONS

1. Electrical energy is being generated, as shown by the movement of the meter indicator. What is the source of this energy?
2. Can you suggest a practical use for this apparatus?
3. (Optional.) Explain the difference in results for Procedures D and E. In your explanation, include a discussion of the reaction between copper ions and electrons.

INVESTIGATION 13.5: Chemical Potential Energy

(pages 319–321)

Electrochemical cells and batteries are important in our technological society. This investigation should help students understand the principle of operation of a battery.

MATERIALS

The milliammeter should be 1 milliampere full scale. One liter of each solution should suffice for the entire class.

PROCEDURES

A. No comment.

B. Until the paper toweling has been added (so that ions can flow through it and balance the flow of electrons), the meter will indicate zero.

C. The toweling acts as a wick. As soon as the toweling is completely wet, the needle will move rapidly and show that current is flowing. Folding the toweling improves capillary action; the dimensions of the toweling are not critical and can be adapted to fit the test tubes you use. However, it is important that the toweling be folded three times; one or two folds may not produce enough current.

Fresh toweling must be used in Procedures D and E. In each case the toweling should have the same dimensions as the toweling used in this procedure.

D. The test tubes should be filled to the same depth as they were in Procedure C. Current will be slightly less than in Procedure C.

E. The test tubes should be filled to the same depth as before. Current will be much less than in Procedure D.

INTERPRETATIONS

1. The source of the energy is chemical potential energy. If the concentrations are equal, the iron will lose electrons, forming iron ions in solution. And copper ions in solution will gain electrons, becoming copper metal. Thus electrons tend to flow from the iron wire through the meter to the copper wire.
2. A type of battery. Many wet-cell batteries work on the same general principle.
3. Diluting the copper ions had a greater effect than did diluting the iron ions. Copper ions must be present to accept electrons if the reaction is to occur. Iron ions are produced by the reaction instead

of being used up in it. When the iron solution was diluted, the concentration of iron ions was less; but as the reaction occurred, iron metal lost electrons and produced more iron ions. When the copper solution was diluted, copper ions were less likely to hit the electrode and accept electrons, so the reaction slowed down.

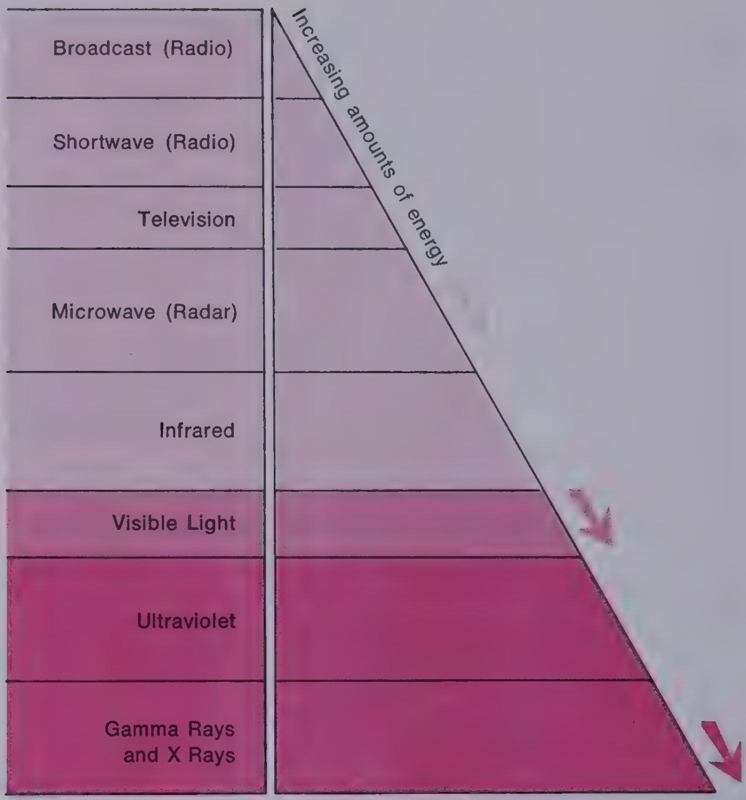

Figure 13 • 11. The electromagnetic spectrum. When electromagnetic energy interacts with matter, work is done. The kind of interaction depends on the amount of energy involved. When an X ray or a gamma ray strikes matter, a relatively large amount of energy is released. When a radio wave strikes matter, a much smaller amount of energy is released. The electromagnetic spectrum is a continuous series of energies—from the very small amount in a radio wave to the large amount in a gamma ray.

Electromagnetic Energy

White light seems to be a combination of all colors. You saw these colors when you looked at a white light through a diffraction grating. The energy that comes from a source of light is not limited to the kind of energy you can see. Heat is given off

by a flame or an electric light. On a cloudy day, it is possible to get a sunburn even though you feel cool. Visible light and the kinds of energy that produce warmth and sunburn are examples of electromagnetic energy.

The sun is 93 million miles from the earth. Even so, we can still use energy from the sun because electromagnetic energy travels through space.

Many other kinds of energy are also types of electromagnetic energy. All these are shown in the electromagnetic spectrum (Figure 13 • 11). Radio, television, and radar signals travel from transmitters to receivers as low-energy electromagnetic waves. Infrared radiation is an electromagnetic wave. When it is absorbed by matter, heat is produced. Waves of infrared and visible light have more energy than waves of radio, television, or radar. Ultraviolet rays and X rays are electromagnetic waves with even greater amounts of energy. Infrared radiation is used in cooking food and heating buildings. Sunlight and electric lights are part of our requirements for normal living. Ultraviolet radiation is useful in killing certain disease organisms. Gamma rays and X rays have so much energy that they travel right through solid objects. They can be used to detect and treat cancer; X rays are used in industry to find hidden cracks in metal, and in medicine to reveal broken bones.

Usually we use electricity to generate electromagnetic energy. The source of most of our energy is the sun. Heat from the sun causes water to evaporate. When the water falls to the earth, as rain, some of it is trapped behind dams and then used to operate electric generators. Other generators are powered by coal. But the energy stored in coal came from the sun, too.

Until recently, the source of the tremendous amount of energy given off by the sun was a puzzle. If the sun depended on chemical reactions, it would have used up all its energy long ago. Experiments with electromagnetic radiation led to the theory that mass can be converted into energy. About forty years after the theory was proposed, nuclear energy was harnessed by man. Chemical energy comes from electron rearrangements. Nuclear energy comes from a change in the nucleus of an atom. Nuclear reactions

release millions of times more energy per pound of fuel than chemical reactions. We now believe that the sun's energy comes from the nuclear reactions in which hydrogen is changed into helium.

There are advantages and disadvantages in using nuclear energy. Whenever nuclear reactions take place, high-energy electromagnetic radiation is released. This radiation can have harmful effects on living things. Nuclear power plants are surrounded by heavy shielding to absorb this radiation. If heavy protective shielding were not needed, airplanes and land vehicles would now be powered by nuclear energy. New ways to control nuclear energy are being developed. It may be that the automobile of the future will run on nuclear energy and will need refueling only once or twice a year.

Nuclear energy is beginning to compete with coal as an economical source of power to generate electricity. It is also being used to operate engines in large ships. Scientists continue to seek new and better methods of obtaining and using energy. At the present rate of scientific progress, uses and sources of energy undreamed of today may be commonplace within your lifetime.

You have seen that each division of the electromagnetic spectrum is composed of waves with different amounts of energy. Only those waves that can be seen by the naked eye belong to the division of the electromagnetic spectrum called *visible light*. Violet light produces the shortest waves that can be seen by the naked eye. Ultraviolet light and X rays produce waves even shorter than violet light, but these are not visible to the naked eye. Therefore, the term *spectrum* is not limited to those waves belonging to visible light but includes any or all of the divisions of the electromagnetic spectrum.

All spectra can be broken down into lesser divisions, and these in turn can be subdivided into what are known as continuous and bright line spectra. Examples of the first two of these subdivisions are shown in Figure 13 • 12.

Continuous spectrum.

Bright line spectrum of hydrogen.

Bright line spectrum of mercury.

Bright line spectrum of helium.

Figure 13 • 12. When white light is bent with ■ diffraction grating, ■ rectangle appears that is made up of ■ pattern of colors. None of these colors is white. Red light appears at one end of the rectangle and violet light at the other, with a continuous sequence of colors in between. An unbroken spectrum of colors, such as this, is called ■ *continuous spectrum.*

When light from glowing gases such as hydrogen, mercury, and helium passes through a diffraction grating, a *bright line spectrum* results. Bright line spectra are composed of distinct and separate color lines. These lines of colors are "fingerprints" that identify the gas present. Are the colors that appear in each of the bright line spectra shown in this figure also present in the continuous spectrum?

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Electromagnetic Energy

(pages 322–324)

We have avoided suggesting experimental work with radioisotopes as a means of studying nuclear energy. Investigations of this nature are often performed at higher grade levels, where students are better able to appreciate the hazards that are involved in working with radioactive materials.

Detailed analysis of nuclear reactions has been muted in favor of a broad discussion of the electromagnetic spectrum. Students who take courses in chemistry and physics later on are likely to study nuclear reactions in more detail.

SUPPLEMENTARY MATERIALS

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FILMS

Light and Color. Encyclopaedia Britannica Film #1876. 14 minutes. Color. This is a fine concluding activity for this section, but it should not be shown before all laboratory activities are completed. Light and color are shown reflecting from various colored objects. The effect of the prism and the production of light by heating various elements are also shown.

The Story of Light. General Electric. 10 minutes. Color. See your local power company for free loan.

FILM LOOPS

An Inquiry into Color. Interaction Film Loops, Inquiry in Physical Science. Chicago: Rand McNally & Co., 1972.

The Visible Spectrum. Interaction Film Loops, Inquiry in Physical Science. Chicago: Rand McNally & Co., 1972.

SUGGESTED ACTIVITIES FOR TESTING LABORATORY SKILLS AND TECHNIQUES

INVESTIGATION 13.2
Place a crystal on the loop of a flame tester.

INVESTIGATION 13.2
Using the flame test, identify the positive ion in a crystal.

INVESTIGATION 13.3
Complete a circuit by connecting a milliammeter to it.

INVESTIGATION 13.3
Read the current flowing in a circuit containing a milliammeter.

INVESTIGATION 13.4
Identify the positive and negative terminals of a milliammeter. (The terminal symbols should be masked.)

SECTION FOURTEEN

Science and Humanity

SECTION FOURTEEN

Science and Humanity

(pages 327–341)

Preview

Section Fourteen introduces some topics not generally included in a science course: the relationship of science to other areas of human endeavor—art, for example; the questions raised by the scientific achievements of the last century; the implications of these achievements for the future. All these are areas that might be discussed in a social studies class. We feel, however, that they are appropriate in a science class as well and that their consideration, at the end of a year's work in science, serves to emphasize the intimate relationship of science to daily life and to the major issues confronting society.

The text discusses the human character of scientific activity. The scientist requires freedom to work and an open, critical forum in which to judge his work and the work of others. The originality of the scientist both in asking questions and seeking answers is an important component of his success.

The photo essay "Science and the Citizen (pages 232–235) raises many controversial questions for the class to consider. Lively classroom discussion can—and should—develop from this material.

How Section Fourteen is used depends very much on the nature of your particular class. Informal discussion, debates, panel discussions on various problems, and trade offs are possibilities. You may want to encourage individual or team research projects on the questions raised in the section. Students should be able to find many other examples of problem areas in newspapers and periodicals. The role of emerging nations or the problems of worldwide protein distribution and use are two such areas. These can be researched, reported on, debated, and discussed.

It is important for your students to realize that most of the problems raised in this section are not susceptible to simple yes-or-no answers. Solutions to environmental problems, for example, require

comprises and sacrifices from some or all parties involved. You may want to emphasize this by playing "the devil's advocate" on occasion, taking an opposing position on any given point.

The students you are teaching will be voters in a few years. Few of them will become scientists, but all of them will be affected, for better or worse, by developments in science and by society's use of these developments. For these reasons, we hope this section will provoke thought, research, controversy, and perhaps, on some issues, consensus, in your classroom.

LEARNING OBJECTIVES

Given the opportunity to inquire, to investigate, to interpret data, and to offer hypotheses about the activities in this and other sections of IME, most students should be able to—

- describe and discuss some of the more pressing problems faced by human society;
- discuss the problems of unequal distribution and unequal use of natural resources;
- make some trade off concessions when presented with desirable but incompatible alternatives;
- persist in trying to solve problems;
- participate in additional scientific, technological, or social research;
- demonstrate positive attitudes towards science, venture new ideas, and demonstrate curiosity and concern for the world and its people;
- freely exhibit the intellectual skills of perception, organization, conceptualization, and application.

Science is a human activity. It is done with human minds, hands, and hunches. Science is a way of exploring the universe and all that is in it, all that seems to defy definition. On pages 5 and 6 of this book, we tried to define what science is. Now you have spent most of a school year doing more than fifty investigations in an effort to learn more about what science is.

A question to be asked after all your study is, Have you *done* any science. Have you ever felt like Galileo or Isaac Newton? Have you personally felt the excitement that comes from pursuing an idea with your whole mind and all the resources available to you? If you have, then the definition of the scientific method put forth by the American physicist P. W. Bridgman might provide the clearest statement of what science is. Bridgman said:

> *The scientific method is simply doing your damnedest with your mind with no holds barred.*

Science is many things, but above all else it is the human search through the structure of the universe for greater understanding.

During the months you worked through this course, your friends, teachers, and dozens of other people in your community influenced your life in many ways. Thus the time you spent learning about science was also a time in which you experienced and learned a great deal about people.

Figure 14 • 1. Isaac Newton. "... oceans of the unknown ... islands of truth."

It is important to remember that science is a human enterprise. People and societies are always present. Science cannot happen without people. Isaac Newton once said that the purpose of the scientist is to "sail the oceans of the unknown and discover the islands of truth." Jerome Bruner, a noted American psychologist, disagreed and maintained that scientists explored the unknown and *invented* the islands of truth.

Both of these ideas are valid. The universe has within it a certain consistency in the ways that matter and energy interact. It is true that humans discovered these interactions; but humans also *invented the expression* of these relationships—as laws,

theories, and models—that now provide the substance of scientific "truth." Often the idea of "truth" runs into stormy waters. Because scientists often appear to be interested in the truth of the universe instead of the truth as it applies to human existence, they are sometimes falsely accused of being inhumane.

Try this: put yourself in the place of Galileo during the Inquisition of the 1600's. Galileo wrote a paper that supported the findings of Nicolaus Copernicus, who maintained that the sun was the center of the solar system and that planets (including the earth) circled the sun. The judges of the Inquisition held that this view was totally untrue and demanded that Galileo renounce his statements and apologize for being careless with the social and scientific beliefs of the time.

Figure 14 • 2. Galileo. ". . . but it *does* move."

Centuries of formal science dating back to the Babylonians and Egyptians and including such great men as Aristotle, Ptolemy, and Tycho Brahe had clarified the idea that the sun orbited the earth. In addition, the religious leadership of Galileo's society approved of the earth-centered view. Obviously the irresponsibility of Galileo's "invention" could not be tolerated. Judged guilty by the Inquisitors, he formally gave up his radical idea that the earth moved around the sun. Galileo is said to have muttered, as he left the chambers, "But it *does* move." (Centuries later the philosopher Bertrand Russell remarked that it was not Galileo who said these words: the world said them.)

The universe is not right or wrong; it simply *is*. Human observations and interpretations are subject to change as knowledge grows. Change is a part of the human condition. Through your experiences of the past few months, you have been exposed to scientific concepts and experiences far more refined than Galileo ever knew. How would you feel about defending science or your discoveries as Galileo did centuries ago, on the basis of what you know?

Because science is done by humans, it is extremely difficult to separate science from the humanities. A scientist must live with one foot in each world. He cannot experience and explore the messages of the universe and at the same time ignore his part in human society.

Today's scientists work with extremely complex tools that range from electron microscopes and computers to particle accelerators five times the length of a football field. But this does not mean that scientists are tools or computers. They are human, not robots. Even though today's scientists can invent a robot, they themselves remain humans who can laugh with a child, love another human, and stand in awe at a sunset. Scientists do different things. Those who study Stonehenge (see pages 180–181) focus on how these huge stone slabs form an observatory in which the behavior of stars, planets, and the moon can be predicted. Other kinds of scientists are concerned with the reasons that ancient people transported tons of rock to a barren plain in southern Britain. What religious beliefs, what image of society, what visions of the unknown drove these humans to the heroic effort that gave birth to Stonehenge?

Vision and awareness are vital components of science. Trivial and sometimes insignificant happenings seldom slip past the human mind that is "turned on." A poet can tease an epic idea from a plant clinging to a perch in an often-traveled place:

Flower in the crannied wall,
I pluck you out of the crannies,
I hold you here, root and all, in my hand,
Little flower—but if *I could understand*
What you are, root and all, and all in all,
I should know what God and man is.

Alfred, Lord Tennyson

Figure 14 • 3. Lord Tennyson. ". . . *if* I could understand . . ."

How many walked past and never developed a deeper insight into the world and self because they simply weren't turned on to what was around them?

Henri Becquerel possessed vision when he noticed that certain gray rocks had the power to fog and damage photographic film. This slightly built French physicist became excited when the unexpected happening interrupted the studies he was conducting. Becquerel turned the unexpected discovery into a full-fledged research project that resulted in a whole new concept in science—

radioactivity. One of the jokes scientists often tell is that Becquerel with his vision discovered radioactivity and that a lesser scientist would only have discovered that one shouldn't store certain gray rocks next to photographic film.

When the ideas about radioactivity became more fully developed, scientists began probing deeper into the structure of matter. Many of the investigations you carried out in this course were, in some earlier time, steps in the human quest to learn more about the atom. Since the day that Becquerel concerned himself with the energy released by the minerals in the strange gray rocks, humans have learned to use the energy of the atom for various purposes, from creating electrical power in Idaho to detecting a tumor in the brain of a teen-ager in Georgia. Radioactive treatments are now commonplace techniques for destroying cancer cells and also for detecting dozens of other internal disorders.

And yet the energy locked within atoms can create scenes of terrible destruction and human suffering. The manner in which energy and power is used is often confused with the energy and power itself. This is where the world of human values enters the realm of science. In recent years, tremendous research projects have been conducted in the name of science that have resulted in the production and development of weapons of warfare. The huge rockets that provided the power to lift men to the moon were originally designed to carry nuclear warheads to destroy cities halfway around the world. Because of the costs involved, it would have been impossible to develop the carriers for space exploration if it had not been done as part of the defense program of the United States.

Figure 14 • 4. Neil Armstrong. A giant step?

Much research being done at colleges and universities in different parts of the country is supported by the military. Some of this research is in the area of cancer study, weather prediction, and the control of diseases. Thus the whole question of the relationship between science and human values rises quickly into view. Was Neil Armstrong's "giant step for mankind" an appropriate technological adventure for all humans? Or should the United States have invested its resources in other ways—ways more closely related to lessening human suffering?

Science and the Citizen

Figure 14 • 8. Today, citizens of all countries are faced with important decisions affecting the quality and direction of life on earth. The problems of environment, conservation of resources, pollution, and population will not go away; they will demand more attention and effort in coming decades.

In a few years, you will become a voter. Often your vote will play a part in decisions related to science, technology, and their impact on the quality of life. It will not be enough merely to flip a coin or borrow someone else's opinion in making these decisions. A good citizen must be informed; to be informed, that citizen must *know* something about the issues to be voted on. All too often, environmental programs or projects are attacked because they "cost too much" or are defended because they save us from "total disaster." In fact, the real arguments are seldom simple or clear-cut.

Shown on these pages are pictures related to issues and situations you will be facing. Not all of them are "problems" in the sense that industrial pollution or population is a problem, but all of them will require the thought, energy, and money of the citizens of this and other countries. You, as a voter, will decide the outcomes.

Consider the pictured subjects, one by one. Note that most of them are not yes-or-no, all-or-nothing, issues. Note further that many are related to one another, sometimes very closely. Discuss each question with members of your class.

To achieve this spacious housing development, what priorities must have been established?

Billions of dollars each year are required to support our defense establishment. Much less is spent directly on scientific and medical research. Yet scientific research is important in improving our lives, and medical research can do much to lessen human suffering. What priorities must be established? List some possible trade offs.

This is a swampland natural area. How would priorities on housing conflict with the preservation of areas like this? What would you decide on use of this space?

Science and the Citizen

Trade offs • Since we as a nation may well be working on all these problems at the same time, voters may have to establish *priorities.* To do this, we will be forced to make *trade offs,* that is, we may have to give up one benefit in order to preserve others. We won't be able to have the greatest good for all the people that could exist in this world. The amount of human energy and money that can be devoted to these problems is limited. How would you rank these subjects? Is research for military defense more important than medical research? (Remember that improvements in emergency medical treatment and prevention of disease have been developed by the armed forces.) Is adequate housing more important than mass transit? (Remember that housing outside of cities helps choke our roads with cars, because there is a shortage of good mass transit service.) Can we preserve the natural beauty of our land, forests, mountains, swamps, seashores and still maintain the standard of living we have become accustomed to?

Compare your priorities with those of your classmates. For each problem area, list the various possible trade offs. Discuss why a knowledge of science, technology, and the environment will be important for the informed voter.

What priorities have been established by people in this photo? List the trade offs that each group has made. What alternatives can you suggest?

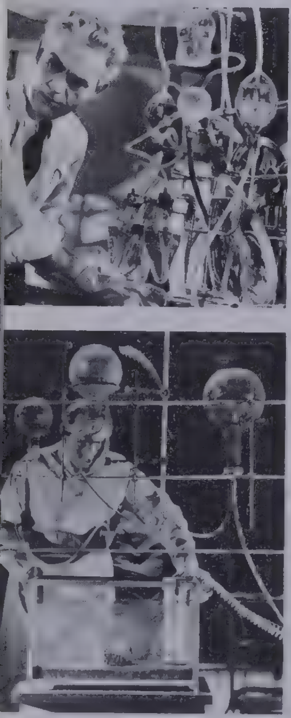
Would you give up some house power, close some factories, and leave most automobiles at home to achieve clean air? What trade offs have been made in the photo at the right? If this factory can not economically clean up the water, what suggestions can you offer?

The amount of coal, gas, and oil to produce electricity is limited. What other sources might be used? What would be the effect on our society of a reduction in available power? Of unlimited cheap power?

Human values and scientific values cannot be separated. Jacob Bronowski, a philosopher of science and values, believes that when values influence human beings, two things happen at once. The values of a group of people tend to blend the individuals in that group into a society, and yet at the same time their values allow the individuals to have separate identities. Scientists furnish an example of this idea. They are members of a scientific society, but they also are individual humans who happen to have chosen to study the world in which they live.

Scientists have never been able to remain isolated from the society in which they work. Galileo was a center of controversy both because he was a scientist and because he was a human. In the 1950's, physicist Robert Oppenheimer became widely known for criticizing the use of nuclear power in warfare. More recently Nobel prize winner Linus Pauling and many other scientists have created controversy by actively protesting national policies, such as the American involvement in Southeast Asia.

Figure 14 • 6. Two Hollywood scientists.



Scientists require certain values to be able to explore. They cherish free inquiry, free thought, and free speech when doing their work. This freedom makes possible the high level of communication that is vital for scientists. The picture of the isolated human hiding in his laboratory making secret concoctions fits the image of low-budget Hollywood films rather than reality. Scientists spend much of their time openly communicating their ideas to colleagues through articles in journals, letters, speeches, and telephone calls. Hundreds of scientific meetings take place in all parts of the world each year.

Strangely enough these meetings turn out to be anything but the dry, noncontroversial sessions you might expect. Scientists disagree with each other as much as anybody else. Often sessions are punctuated with applause, shouts of disagreement, and even a little name-calling. (You probably experienced this aspect of scientific life as you did some of the experiments in this course.) Do you remember times when your data, interpretations, or conclusions after an investigation didn't agree with some other classmate's? The arguments you probably had with your lab partner about experiments were typical of a scientist's life.

Figure 14 • 7. The scientist's role in public affairs is growing. Shown here is a conference of scientists and national leaders, called to discuss the environmental problems of the United States.

Freedom is a deeply important value to all humans, and it is no less important to the scientist. Freely studying the universe is an appropriate activity for humans. It seems a hasty judgment when someone says that scientists are not interested in the human condition. Science and technology are a vital part of contemporary society. Many changes are taking place in America as young people adopt new life-styles and deepen their concern for human values. At the same time, new fields of exploration are appearing, and knowledge in science is growing. If mankind is to survive, the new life-styles and concern for human values cannot be considered to be forces in opposition to new scientific exploration.

There *are* footprints on the moon, and there are suburbs sprawling onto the rich farmlands in every state in the nation. There are people dying of *and* others being cured of cancer. Most of the science being done in the United States today is focused

on guiding technology to serve human needs. Buckminster Fuller, one of the leading scientific spokesmen for the optimistic and hopeful view of the human condition, sees humans developing a greater oneness with the world in which they live. He sees us refocusing technology to allow humankind to run itself "more efficiently." When Fuller talks about the energy crisis that we are facing, he creates a mental image of one million automobiles standing at stoplights and stop signs in all parts of the United States. While they stand there waiting for the light to change or for the traffic to clear, their engines idle, loading the air with pollutants and burning tons of irreplaceable fossil fuel. Fuller sees all this as inefficient.

The most important goal is to relate science to the human condition in ways that are more effective than those of the past. Treating pollution as a problem of efficiency is a new and exciting way to perceive the environment. By thinking of the air as a transparent garbage can and an inefficient technology as the garbage producer, the problem takes on new dimensions.

The science you learned in this course was intended to provide you with new ways of seeing the world in which you live. The process of science is filled with a search for originality. Originality is just as important in *seeing* problems as in *solving* them. Often originality is misunderstood when it first happens.

Figure 14 • 8. Buckminster Fuller. ". . . more efficiently."

Figure 14 • 9. *The Starry Night* was painted by Vincent van Gogh in 1889, the last year of his life.

Vincent van Gogh was one of the most original painters of his time, but his originality was often described as a symptom of madness. His temperament was supposed to have worsened in his later years, and his paintings became more bizarre and frightening. Some of the last of his paintings showed great rings of light circling the sun and stars. Few people of the time realized that Van Gogh was probably painting exactly what he saw, as circles

around light sources are one of the symptoms of glaucoma, a disease of the eye that leads to blindness. Perhaps Van Gogh's behavior was the result not of madness but of an *awareness* that he was going blind.

As a painter, Van Gogh was much like a scientist. He had certain tools with which to work. His paints were the same as the paints of other artists, his canvases the same. But he possessed a vision and an originality that have remained fresh for a century. Another artist, the American Frederic Remington, painted beautiful and exciting pictures of the early West. Again, his tools were the same as other artists used, and his techniques were not much different. But Remington had trained himself to *see* what others had missed. Long before high speed cameras, Remington discovered that when horses galloped, they often had all their feet off the ground at once. At other gaits, they sometimes only had one foot on the ground at any one time. Some criticized his paintings as being inaccurate. But years later, high speed photographs proved him right.

Comparing artists with scientists and scientists with artists is a fruitful activity. In this course, your experiences in science have been much like art lessons. You learned basic techniques and explored fundamental knowledge in the area of science. You probably didn't make any profound discoveries, but you did experience some of the ways to do science. We hope you also experienced the humanness of the activity called *science*. Early in this course (page 9), it was noted that some human groups used spirits to explain the behavior of the universe. Even today, for some people it is still an issue whether spirits or gravity is a better concept to explain motion. Through science, we have discovered that the force we call *gravity* is more consistent. However, as long as there are humans, there will be different models to explain what is happening in the natural world.

It is the guarantee of differences of opinion and intensity of concern that makes science such a challenging pursuit. The real excitement comes from charting your own course to explore unknown areas. Though there may be long periods of routine activity in the journey, there are also those moments of explosive

insight and deep respect that come from discovering how the world works. The new challenge of science is to realize it is both a deeply fulfilling, personal activity and a fruitful avenue toward a better world in which to live.

Figure 14 • 10. Frederic Remington's painting *Gathering the Rope.*

Figure 14 • 11. The early photographer Eadweard Muybridge proved Remington's observations correct.

Appendixes

COMPLETE PERIODIC TABLE OF THE ELEMENTS

KEY

Electron Grouping	2 8 3
Atomic Weight	27.0
Symbol	Al
Atomic Number	13
Name	Aluminum

1 1.0 **H** 1 Hydrogen								
2 1 6.9 **Li** 3 Lithium	2 2 9.0 **Be** 4 Beryllium							
2 8 1 23.0 **Na** 11 Sodium	2 8 2 24.3 **Mg** 12 Magnesium							
2 8 8 1 39.1 **K** 19 Potassium	2 8 8 2 40.1 **Ca** 20 Calcium	2 8 9 2 45.0 **Sc** 21 Scandium	2 8 10 2 47.9 **Ti** 22 Titanium	2 8 11 2 51.0 **V** 23 Vanadium	2 8 13 1 52.0 **Cr** 24 Chromium	2 8 13 2 54.9 **Mn** 25 Manganese	2 8 14 2 55.8 **Fe** 26 Iron	2 8 15 2 58.9 **Co** 27 Cobalt
2 8 18 8 1 85.5 **Rb** 37 Rubidium	2 8 18 8 2 87.6 **Sr** 38 Strontium	2 8 18 9 2 88.9 **Y** 39 Yttrium	2 8 18 10 2 91.2 **Zr** 40 Zirconium	2 8 18 12 1 92.9 **Nb** 41 Niobium	2 8 18 13 1 96.0 **Mo** 42 Molybdenum	2 8 18 13 2 98.9 **Tc** 43 Technetium	2 8 18 15 1 101.1 **Ru** 44 Ruthenium	2 8 18 16 1 102.9 **Rh** 45 Rhodium
2 8 18 18 8 1 132.9 **Cs** 55 Cesium	2 8 18 18 8 2 137.4 **Ba** 56 Barium	2 8 18 18 9 2 138.9 **La** 57 Lanthanum	2 8 18 32 10 2 178.5 **Hf** 72 Hafnium	2 8 18 32 11 2 181.0 **Ta** 73 Tantalum	2 8 18 32 12 2 183.9 **W** 74 Tungsten	2 8 18 32 13 2 186.2 **Re** 75 Rhenium	2 8 18 32 14 2 190.2 **Os** 76 Osmium	2 8 18 32 15 2 192.2 **Ir** 77 Iridium
2 8 18 32 18 8 1 (223) **Fr** 87 Francium	2 8 18 32 18 8 2 (226) **Ra** 88 Radium	2 8 18 32 18 9 2 (227) **Ac** 89 Actinium						

2 8 18 20 8 2 139 **Ce** 58 Cerium	2 8 18 21 8 2 141 **Pr** 59 Praseodymium	2 8 18 22 8 2 144 **Nd** 60 Neodymium	2 8 18 23 8 2 (147) **Pm** 61 Promethium	2 8 18 24 8 2 150 **Sm** 62 Samarium
2 8 18 32 18 10 2 232 **Th** 90 Thorium	2 8 18 32 20 9 2 (231) **Pa** 91 Protactinium	2 8 18 32 21 9 2 238 **U** 92 Uranium	2 8 18 32 22 9 2 (237) **Np** 93 Neptunium	2 8 18 32 24 8 2 (239) **Pu** 94 Plutonium

Appendix A

								2 4.0 **He** 2 Helium
			2 3 10.8 **B** 5 Boron	2 4 12.0 **C** 6 Carbon	2 5 14.0 **N** 7 Nitrogen	2 6 16.0 **O** 8 Oxygen	2 7 19.0 **F** 9 Fluorine	2 8 20.2 **Ne** 10 Neon
			2 8 3 27.0 **Al** 13 Aluminum	2 8 4 28.1 **Si** 14 Silicon	2 8 5 31.0 **P** 15 Phosphorus	2 8 6 32.1 **S** 16 Sulfur	2 8 7 35.5 **Cl** 17 Chlorine	2 8 8 39.9 **Ar** 18 Argon
6 58.7 **Ni** 28 ickel	2 8 18 1 63.5 **Cu** 29 Copper	2 8 18 2 65.4 **Zn** 30 Zinc	2 8 18 3 69.7 **Ga** 31 Gallium	2 8 18 4 72.6 **Ge** 32 Germanium	2 8 18 5 74.9 **As** 33 Arsenic	2 8 18 6 79.0 **Se** 34 Selenium	2 8 18 7 79.9 **Br** 35 Bromine	2 8 18 8 83.8 **Kr** 36 Krypton
8 8 106.4 **Pd** 46 alladium	2 8 18 18 1 107.9 **Ag** 47 Silver	2 8 18 18 2 112.4 **Cd** 48 Cadmium	2 8 18 18 3 114.8 **In** 49 Indium	2 8 18 18 4 118.7 **Sn** 50 Tin	2 8 18 18 5 121.8 **Sb** 51 Antimony	2 8 18 18 6 127.6 **Te** 52 Tellurium	2 8 18 18 7 126.9 **I** 53 Iodine	2 8 18 18 8 131.3 **Xe** 54 Xenon
8 2 7 195.1 **Pt** 78 Platinum	2 8 18 32 18 1 197.0 **Au** 79 Gold	2 8 18 32 18 2 200.6 **Hg** 80 Mercury	2 8 18 32 18 3 204.4 **Tl** 81 Thallium	2 8 18 32 18 4 207.2 **Pb** 82 Lead	2 8 18 32 18 5 209.0 **Bi** 83 Bismuth	2 8 18 32 18 6 (209) **Po** 84 Polonium	2 8 18 32 18 7 (210) **At** 85 Astatine	2 8 18 32 18 8 (222) **Rn** 86 Radon

2 8 18 25 8 2 152 **Eu** 63 Europium	2 8 18 25 9 2 157 **Gd** 64 Gadolinium	2 8 18 27 8 2 159 **Tb** 65 Terbium	2 8 18 28 8 2 162 **Dy** 66 Dysprosium	2 8 18 29 8 2 165 **Ho** 67 Holmium	2 8 18 30 8 2 167 **Er** 68 Erbium	2 8 18 31 [illegible] 2 169 **Tm** 69 Thulium	2 8 18 32 8 2 173 **Yb** 70 Ytterbium	2 [illegible] 18 32 9 2 175 **Lu** 71 Lutetium
2 8 18 32 25 8 2 (241) **Am** 96 Americium	2 8 18 32 25 9 2 (244) **Cm** 96 Curium	2 8 18 32 26 9 2 (249) **Bk** 97 Berkelium	2 8 18 32 28 8 2 (249) **Cf** 98 Californium	2 8 18 32 29 8 2 (254) **Es** 99 Einsteinium	2 8 18 32 30 8 2 (253) **Fm** 100 Fermium	2 8 18 32 31 8 2 (256) **Md** 101 Mendelevium	2 8 18 32 32 8 2 (254) **No** 102 Nobelium	2 8 18 32 32 9 2 (257) **Lw** 103 Lawrencium

Appendix B

Below are the names of a few scientists and their fields of interest:

1. Aristotle (384–322 B.C.)
   Chemistry and physics
2. Archimedes (287–212 B.C.)
   Mathematics and physics
3. Lucretius (*c.* 99–55 B.C.)
   Chemistry
4. Roger Bacon (*c.* 1220–1292)
   Physics
5. Galileo Galilei (1564–1642)
   Physics
6. Blaise Pascal (1623–1662)
   Mathematics and physics (fluids)
7. Christian Huygens (1629–1695)
   Physics (light)
8. Sir Isaac Newton (1642–1727)
   Physics (laws of motion)
9. Alessandro Volta (1745–1827)
   Physics (electricity)
10. John Dalton (1766–1844)
    Chemistry (atomic theory)
11. Amedeo Avogadro (1776–1856)
    Chemistry (atomic theory)
12. Jöns Jakob Berzelius (1779–1848)
    Chemistry
13. Michael Faraday (1791–1867)
    Chemistry (electricity and physics)
14. Sir Joseph John Thomson (1856–1940)
    Physics (atomic theory)
15. Svanté August Arrhenius (1859–1927)
    Chemistry
16. Ernest Rutherford (1871–1937)
    Physics (atomic theory)
17. G. N. Lewis (1875–1946)
    Chemistry
18. Linus Pauling (b. 1901—)
    Chemistry

Appendix C

Conversion Tables: Units of Measurements

LENGTH

English to Metric

1 mile	= 1.6094 kilometers
1 yard	= 0.9144 meter
1 foot	= 0.3048 meter
1 inch	= 2.5400 centimeters

Metric to English

1 kilometer	= 0.6214 mile
1 meter	= 1.0936 yards
1 centimeter	= 0.3937 inch
1 millimeter	= 0.03937 inch

Metric to Metric

1 kilometer	= 1000 meters
1 meter	= 100 centimeters
1 centimeter	= 10 millimeters
1 meter	= 1 million microns
1 meter	= 1000 millimeters
1 micron	= 1000 millimicrons

VOLUME

English to Metric

1 gallon	= 3.7853 liters
1 quart	= 0.9463 liter
1 pint	= 0.4731 liter
1 ounce (fluid)	= 29.6 milliliters
1 cubic inch	= 16.3868 milliliters

Metric to English

1 liter	= 1.0567 quarts
1 milliliter	= 0.0338 ounce (fluid)
1 cubic centimeter	= 0.0338 ounce (fluid)

Equivalents

1 liter	= 1000 milliliters
1 milliliter	= 0.061025 cubic inches

MASS (AND WEIGHT)

English to Metric

1 pound = 0.4536 kilogram
1 pound = 453.5924 grams
1 ounce (avdp) = 28.3495 grams

Metric to English

1 kilogram = 2.2046 pounds
1 gram = 0.0022 pound
1 gram = 0.03527 ounce (avdp)
1 milligram = 0.000035 ounce (avdp)

Metric to Metric

1 kilogram = 1000 grams
1 gram = 1000 milligrams

ABBREVIATIONS USED FOR UNITS OF MEASUREMENT

Word	*Abbreviation*	*Word*	*Abbreviation*
avoirdupois	avdp	liter	l
centimeter	cm	meter	m
cubic centimeter	cc	micron	μ, or mu
cubic inch	cu in	mile	mi
degree Celsius	C	milligram	mg
degree Fahrenheit	F	milliliter	ml
fluid	fl	millimeter	mm
foot	ft	millimicron	mμ
gallon	gal	ounce	oz
gram	g	pint	pt
inch	in	pound	lb
kilogram	kg	quart	qt
kilometer	km	yard	yd

Prefix in Metric System	*Meaning*
mega-	1,000,000
kilo-	1,000
centi-	0.01
milli-	0.001
micro-	0.000001

TEMPERATURE

Celsius to Fahrenheit

−273.18	−459.72
−250	−418
−200	−328
−150	−238
−100	−148
− 50	− 58
0	+ 32
10	+ 50
20	+ 68
30	+ 86
50	+122
100	+212
150	+302
200	+392
500	+932
1000	+1832
2000	+3632
3000	+5432

Fahrenheit to Celsius

−400	−240
−300	−184.5
−200	−129
−100	− 73.3
− 40	− 40
0	− 17.3
20	− 6.7
32	0
50	+ 10
70	+ 21.1
100	+ 37.8
150	+ 65.6
200	+ 93.3
500	+260
1000	+537.8
2000	+1093.3

CONVERSION FORMULAS

$C = 5/9(F-32)$
$F = 9/5C + 32$

Appendix D

Equipment and Supplies for a Class of 32 Students

Many supply and equipment items needed for this course should be available in junior high or intermediate school science departments. If not available, the supplies and equipment can be purchased from various scientific-supply companies. As a convenience for teachers who would prefer to order from one company rather than from several, the publisher has supply and equipment packages available that contain nearly everything needed to teach IME.

Quantities in the list following are based on a class of thirty-two students and an ideal team size of four students. Materials are listed under the headings, "Apparatus and Instruments," "Chemicals," "Glassware," and "Miscellaneous." Their use is keyed to the proper section and page.

Ordering Procedures

SUPPLY AND EQUIPMENT PACKAGES

Five IME packages are offered:

1. 32-student nonconsumable package (may be used by one or more classes taught consecutively)
2. Teacher demonstration materials package
3. Combination student and teacher package
4. 32-student chemical package
5. 32-student glassware package

Please order all packages and individual items from:

Rand McNally & Company
School Department
P.O. Box 7600
Chicago, Illinois 60680

Some teachers may wish to purchase individual items in addition to or instead of complete packages. A catalog and price list is available upon request.

Item	Quantity	Section and Page												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Apparatus and Instruments														
Balance (sensitive to 1/10 or 1/100 g)	8						138, 144a	163d, 164, 166, 170a	209			262, 264		
Balls, steel (½" in diameter)	16									207c, 218, 220, 221				
Battery (penlight size)	1								173a					
Battery (6-volt lantern type)	1			74			135							
Bulb, neon	1													316b
Bulb, showcase (25 watt, unfrosted)	1													314
Bulb (25 watt)	1													307
Bulb (50 watt)	1												298d	
Bulb (150–200 watt)	1											274	301	
Burner, alcohol	8			76	84b	116, 124b	141, 143, 144a					262, 264, 267		317
Can, overflow	8							158, 170a						
Conductivity indicator system	8					108a, 110, 119b	134							
Dialysis tubing	50 ft	8c	50	73b, 74			135							
Diffraction grating	30												301	316b
Discharge tube, gas	1													316b
Gauze, wire				76		116	141					264		
Grooved track, with force mechanism	8								178, 187	218				

Item	*Quantity*	*Section and Page*												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Grooved track, without force mechanism	8								184, 201, 204	221				
Hand lens	8		35, 39, 50											
Interference plate													300	
Microscope (10X eyepiece and 40X objective)	1		37a											
Microscope light	1		37a											
Milliammeter	8			73b										314, 317, 319
Mirror, metal	8												297	
Mirror, pocket	8												279, 281, 283, 286, 288	
Mirror support	8												286, 288	
Nichrome wire flame tester	9													310
Overhead projector	1												297	
Penlight	8												279	
Plastic box (rectangular with cover)	8												292	
Plastic box (wedge-shaped with cover)	8												292	
Plastic container (4″ x 5″)	8												272	
Prism, metal (round)	8												299	
Prism, metal (triangular)	8												299	
Ring stand, with clamp and ring	8	8b,8c		60			141					264		

Item	Quantity	Section and Page												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Ripple tank apparatus	1												297, 299, 300	
Ruler, plastic (cm and inches)	32		35	59b, 60	108a			154, 158	187, 204		240, 248	274	283, 288, 292	319
Solar cell	8													314
Thermometer, alcohol (uncalibrated)	32										240, 248, 253			
Thermometer, mercury	16											259, 262, 264, 270, 272, 274		
Timer	1								184, 187, 201, 204, 207c	221				
Wire, bell	50 ft		42,45	73b, 74										
Wire, copper	4 ft					108a								317, 319
Wire, iron	4 ft													319
Wire, nichrome	4 ft													317
Chemicals														
Acetone	2 pt				84b						253e			
Ammonium hydroxide	1 pt	13a				116								
Barium chloride	4 oz					108a, 110, 120	135, 138							

Item	*Quantity*	*Section and Page*												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Barium hydroxide	4 oz					119b								
Bromothymol blue	1 dropper bottle					114, 116								
Copper chloride	4 oz													310
Copper nitrate	4 oz													310
Copper sulfate	5 lbs						134, 138, 141, 143, 144a							310, 319
Ditto fluid (methyl alcohol)	3 qt					110, 131		163d, 166			250, 253	270		
Dry ice	5 lbs										253, 253e			
Hydrochloric acid	1 qt	13a				110, 111a, 114, 116, 119a								
Iodine crystals	8 oz		50	73b, 74										
Iron chloride	4 oz													319
Iron filings	2 ml						138							
Lead nitrate	3 g			76										
Litmus paper (300 red and 300 blue)	600 pieces					114, 116	138							
Magnesium chloride	4 oz					120								
Magnesium ribbon	1 small package				84b	124b								
Phenolphthalein solution	2 oz					119b								
pH paper (Hydrion, 1–13 range)	1 roll					119a, 119b								

Item	*Quantity*	*Section and Page*												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Potassium bromide	4 oz					108a, 110								310
Potassium chloride	4 oz													310
Potassium iodide	8 oz		50	73b, 74, 76										
Potassium sulfate	4 oz													310
Sodium bromide	4 oz													310
Sodium chloride	2 lbs					108a, 110, 111a, 114, 120					250			310
Sodium hydroxide	4 oz					108a, 110, 114, 119a, 120								
Sodium sulfate	4 oz													310
Starch (potato or corn)	1 lb					131								
Sulfuric acid	1 pt					119b, 120, 130a								
Glassware														
Beakers, Pyrex (50 ml)	2					119b								
Beakers, Pyrex (125 ml)						130a								
Beakers, Pyrex (150 ml)	16			76		108a, 116, 119a, 124b	134	163d						
Beakers, Pyrex (250 ml)	16	8c	39,42	73b, 74		110	135				241, 250, 253, 253e	262, 264, 270		

Item	Quantity	Section and Page												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Bowls	1	13a												
Droppers, medicine	8			76										
Evaporating dish	8	13a					141, 144a							
Flask, Erlenmeyer (250 ml)	8											267		
Funnel	8		42	76										
Glass plate (8″ x 10″)	8		50											
Graduated cylinder (100 ml)	8						138	158, 163d, 164, 166, 170a	183a			259, 262, 264, 272, 274		
Graduated cylinder (1000 ml)	1													319
Jars (baby food with lids)	32					114	138					259		
Jars (pint)	16		39,45, 50			116, 119b	135, 143							
Microscope slides	64		37a	76		116	135							
Microscope slides—coverglass	5		37a											
Stirring rod (15 cm)	10					130a					240, 250	264		
Test tubes, Pyrex (20 x 150)	60			76		116, 120	138, 141, 143				248, 253			319
Tubing, glass (6 mm in diameter)	8 ft	8c							191			267		
Wall mirror (12″ square)	8												281	
Watch glass	8						138							
Miscellaneous														
Aluminum foil	1 roll					124b							298d, 301	
Aluminum pan	10		42,50											
Bags, paper	32	8a												

Item	*Quantity*	*Section and Page*												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Blocks, small wooden	16							158, 159						
Blocks, styrofoam (irregular)	8							168						
Blocks, wooden (2" x 4" x 6")	32								191					
Box, cardboard (2' x 2' x 2')	16													307
Box, shoe	16												279	307
Candle	8													317
Cans, aluminum (8 white and 8 black)	16											274		
Cans, coffee (2 lb)	3								173a					
Cardboard, corrugated (8" x 8")	8												286, 288, 292	
Cards, index (5" x 7")	1 package								189, 191, 201, 204	221				
Cellophane, colored (one roll each of blue, green, red, and yellow)	4 rolls													307
Chalk	1 box		35											
Cloth, cotton (1" x 4")	24											270		
Cloth, wool (6" x 6")	8			59b, 60										
Cups, aluminum	8											272		
Cups, paper	16								189					
Cups, styrofoam	32											262, 264		
Eraser, artgum (each set should contain three sizes)	8 sets							168						
Erasers, chalkboard	8		50											

Item	Quantity	Section and Page												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Food coloring, green	1 small bottle		47											
Freezer tape	1 roll										241			
Hammer	1										253e			
Knife	8												279	307
Lead weights (8 each of 1 oz, 2 oz, and 4 oz weights)	24	8b							209	231		262		
Marbles (½″ in diameter)	64							159, 168	178, 184, 187, 201, 204	218, 221				
Masking tape	4 rolls			59b, 60, 76		116	135		173a, 189, 191, 204, 209	221		259	279, 281, 286, 288, 292, 300	307
Matches, safety	1 box			76		116	141							317
Metersticks	8	8c						156	191, 201	231				316d
Nails, iron	50						138	159, 168					279	
Newspaper	8											259		
Oil, vegetable	3 qts		39			131								
Paper, carbon	10 sheets									220				
Paper, construction (20 sheets black, 4 blue, 4 green, 4 orange, 4 red, and 4 yellow)	40 sheets	13a												306
Paper, filter (4″ in diameter)	32 pieces		47	76										

Item	Quantity	Section and Page												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Paper, graph	1 box							159, 164, 168	184, 187, 204					
Paper, tracing	10 sheets									220			281	
Paper, white (unruled)	1 box							154	174	221			281, 283, 286, 288, 292, 298d	
Paper clips	1 box		47,50	59b, 73b, 74			135		189, 191, 201	231				
Pencils, colored	1 box							164		220				
Pens, marking	8									220, 231				
Pins, straight	1 box		45					159					286, 288, 292	
Plastic wrap	1 roll		39	59b, 60										
Protractor	8												288	
Razor blades, single edge	1 box												279	
Rubber bands	1 box		50					168	191, 201			270		
Sand	2 lbs								183a					
Sandpaper (8" x 8")	4 sheets								191					
Scissors	8	8c									241			319
Soap, liquid	5 pints		39,42, 45,50											
Steel wool	1 package					124b	138							
String	1 roll	8b,8c							209					

Item	Quantity	Section and Page												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Sugar, table	5 lbs	8c				108a, 110, 130a, 131		159, 163d, 168		250				
Tape, adding machine	1 roll								204					
Test tube holder	8						141, 143							
Test tube rack	8						143							
Thread, white (heavy)	2 spools		42	60				159		231		262		
Tongs	1				84b	124b					253e			
Toothpicks	1 box		39, 42, 50											
Towels, paper	1 roll		39, 45											319
Watch, with sweep-second hand	1									231				
Water, distilled	10 gal			73b, 74, 76		110	135							
Wire, coat hangers	64		42											

Ripple Tank Components

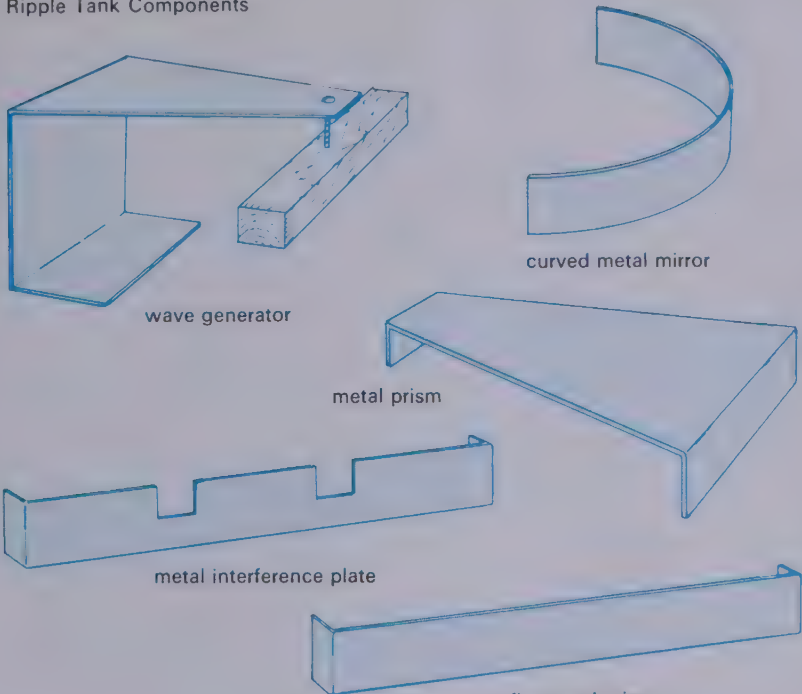
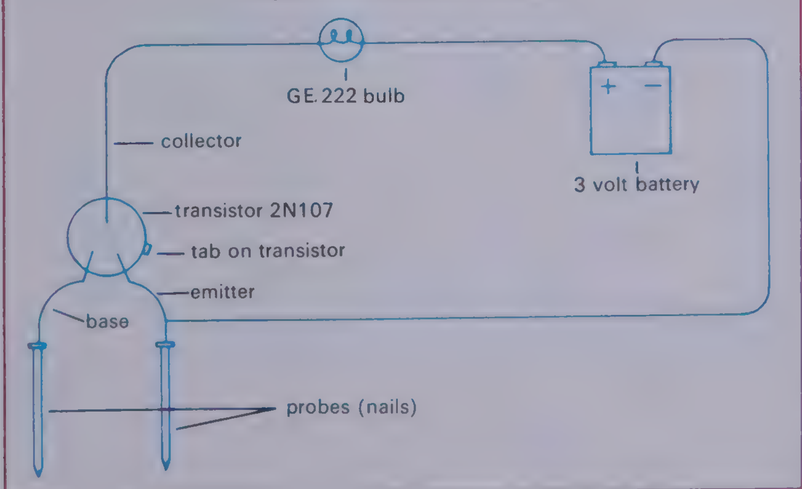


Diagram of Conductivity Indicator



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An * indicates an illustration


SHOOTING
STAR